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HERBICIDE, SALINITY, AND FLOODING TOLERANCE OF FOXTAIL BARLEY

(*Hordeum jubatum* L.) AND DESIRABLE PASTURE GRASSES

by

Karl R. Israelsen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science
(Weed Science)

Approved:

Corey V. Ransom Major Professor	Ralph E. Whitesides Committee Member
Blair L. Waldron Committee Member	Grant E. Cardon Committee Member

Byron R. Burnham
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2009

ABSTRACT

Herbicide, Salinity, and Flooding Tolerance of Foxtail Barley (*Hordeum jubatum* L.) and Desirable Pasture Grasses

by

Karl Israelsen, Master of Science

Utah State University, 2009

Major Professor: Dr. Corey V. Ransom
Department: Plants, Soils, and Climate

Research trials performed in the greenhouse compared the tolerance and response of *Hordeum jubatum* and desirable pasture grass species to herbicides, salinity, and flooding. Desirable grass species used in this study included: ‘Fawn’ tall fescue (*Festuca arundinaceae*), ‘Garrison’ creeping foxtail (*Alopecurus arundinaceus*), ‘Palaton’ reed canarygrass (*Phalaris arundinacea*), ‘Climax’ timothy (*Phleum pratense*), ‘Alkar’ tall wheatgrass (*Thinopyrum ponticum*), ‘Potomac’ orchardgrass (*Dactylis glomerata*), and ‘Mustang’ altai wildrye (*Leymus angustus*). Tolerance to herbicides, salinity, and flooding varied significantly among grass species. Herbicide tolerance was tested using four herbicides at five rates each. The herbicides used were imazapic (Plateau), propoxycarbazone (Olympus), sulfosulfuron (Outrider), and flucarbazone (Everest) at rates of 0, 10, 25, 50, 100, and 200 g ha^{-1}. Foxtail barley was least tolerant of sulfosulfuron and propoxycarbazone. Tall fescue, creeping foxtail, and reed canarygrass were susceptible to all the herbicides tested. Timothy and foxtail barley were moderately tolerant while tall wheatgrass exhibited the greatest tolerance to flucarbazone. Orchardgrass was most tolerant to propoxycarbazone. Salinity tolerance was determined by exposing grasses to increasing electrical conductivity (EC) over time. Reed canarygrass and timothy were most susceptible to salinity. Orchardgrass, creeping foxtail, and tall fescue were moderately tolerant of salinity. Foxtail barley, altai wildrye, and tall wheatgrass exhibited the highest tolerances to salinity, and continued to persist at the highest EC levels tested. Flooding tolerance was determined by flooding grasses in 18 cm of water for 2, 4, 6, and 8 weeks. Grasses that were able to extend above the water surface survived, whereas plants that failed to extend beyond the water surface experienced higher mortality rates.

(95 pages)

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Karl Israelsen

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CHAPTER 1

LITERATURE REVIEW

Origin and Distribution

Hordeum jubatum, commonly referred to as foxtail barley, is from the Poaceae family. It is a weedy, native grass that is prevalent through most of North America (Badger and Unger 1990; Best et al. 1978; Cords 1960). *H. jubatum* commonly establishes in meadows, prairies, native pastures, near riverbeds and in seasonal lakes where saline or alkaline habitats and high water tables often occur (Badger and Unger 1990; Cords 1960; Whitson et al. 2000; USU herbarium). *H. jubatum* is also adaptable to growing conditions along roadsides, uncultivated fields and in other disturbed sites and drawdown areas (Hansen et al. 1988; Hitchcock 1950; Shumaker and Babble 1980). Populations of *H. jubatum* exist commonly on abandoned lands and are frequently one of the first grasses to become established (Wilson 1967). *H. jubatum* grows at elevations of 0–3000 meters and has been introduced to South America, Europe, central Asia, Russia and other countries outside its native range as an ornamental (Best et al. 1978; USU herbarium).

Morphology and Description

Hordeum jubatum is a cool season, native, short-lived perennial bunchgrass (Cords 1960). The mature height of *H. jubatum* often measures 0.3 to 0.6 m tall (Best et al. 1978). A distinctive bluish to grayish-green leaf color makes *H. jubatum* easy to identify early in the spring. Leaf blades are prominently ribbed and rough, measuring 5 mm wide. The leaf sheath is ribbed but not rough and is often hairy and split with overlapping margins at the lower portion. Stems are smooth, round, and hollow with swollen nodes, originating from a mass of shallow fibrous roots. Ligules are short and membranous, less than 1mm long. Auricles are absent or rudimentary (Best et al. 1978; Whitson et al. 2000).

At maturity, *Hordeum jubatum* develops nodding seed heads that turn a greenish to purplish creamy color (Best et al. 1978; Whitson et al. 2000). Flowering occurs from June to August. Seed heads are dense, unbranched, spikes that measure 5 to 12 cm long (Best et al. 1978). When seed heads reach maturity they easily break apart into individual seed units. Each seed unit consists of 7 finely barbed awns and 3 spikelets (1 fertile and 2 sterile) with a sharp point, making seeds easily dispersed by wind and animals (Best et al. 1978; Whitson et al. 2000).

Salinity and Flooding

The ability to reproduce prolifically and adapt to undesirable growing conditions allows *Hordeum jubatum* to establish and flourish in difficult and adverse environments where other vegetation struggles to compete. Fluctuating salinity and flooding levels favor the establishment of *H. jubatum* seed germination and seed bank reserves in these conditions also contribute to the establishment and persistence of *H. jubatum* (Boyd and Van Acker 2003).

As a halophyte, *Hordeum jubatum* has tolerance mechanisms that make it adaptable and tolerant to difficult growing environments. Tolerance mechanisms that have been found to aid in the adaptability of salt tolerant plants include salt exclusion, uptake and compartmentalization of salts, and active extrusion of salts (Badger and Unger 1990). *H. jubatum* has shown tolerance to multiple soil salinity levels (Best et al.

1978), allowing it to become established in areas where competition from other vegetation is limited (Cords 1960). Environmental changes such as salinity and flooding often influence *H. jubatum* dominance (Badger and Ungar 1990, 1994; Ungar and Riehl 1980). Observations from Dodd and Coupland (1966) showed *H. jubatum* establishment was most abundant on the drier edges of a depressed saline area gradient, often resulting in almost pure stands that occurred in large flat depressions or as a ring around deeper depressions. Best et al. (1978) observed that *H. jubatum* occurs most commonly in wet fertile soils. Results from Best et al. (1978) showed greater emergence of *H. jubatum* occurred when soil moisture fluctuated between field capacity (FC) and 1/3 FC compared to fluctuations between FC and 1/6 FC.

Badger and Ungar (1990) established a soil salinity gradient and determined that *H. jubatum* is restricted to moderate zones of salinity where soils contain 0.3 to 0.9 percent total salts. However, results showed *H. jubatum* could survive salinities which exceeded its physiological limits for growth and reproduction by surviving a number of weeks at 1.5 percent NaCl. Fluctuating soil moisture generates variable salinity intervals which interfere with the growth cycles of more desirable vegetation, lessening competition, and creating an environment more favorable to the establishment of *H. jubatum* (Badger and Ungar 1990; Cords 1960; Dodd and Coupland 1966). Cords (1960) determined that emergence of *H. jubatum* was suppressed at a three inch water table and fewer seedlings emerged from saline soils compared to non-saline soils. Higher soil salinity shows an increase in *H. jubatum* mortality (Badger and Ungar 1994; Ungar 2001). Cords (1960) implied that poor emergence of *H. jubatum* in saline soils is compensated by higher seed production which results in higher establishment. In addition, Cords (1960) claims that *H. jubatum* is more sensitive to salinity during the early growth period, but found that higher yields were produced in saline soils during the second year of the study. A study carried out by Wilson (1967) also showed higher yields of *H. jubatum* when grown under saline conditions.

Germination

Boyd and Van Acker (2003) state that germination requirements for specific plant species can differ considerably and germination may not occur unless specific conditions are achieved. Dodd and Coupland (1966) associated a series of dry years to an extended period of emergence for *Hordeum jubatum*, causing increased areas of invasion to occur. Badger and Ungar (1994) found that *H. jubatum* seed germination was decreased with warm temperatures and when soil salinity was greater than 1%. Badger and Ungar (1989; 1994) state that *H. jubatum* does not require light for germination to occur which supports the conclusion made by Hoffman et al. (1980) that *H. jubatum* germinates best in darkness. However, Donald (1990) states that seed on the soil surface can quickly germinate and emerge on no-till land. Germination and emergence of *H. jubatum* was highest when seeds were placed at 1 to 2 cm in soils maintained at field capacity and emergence was significantly lower when seeds were placed on the soil surface (Boyd and Van Acker 2003). Donald (1990) claims that *H. jubatum* emergence was greatest at the soil surface and decreased as seed depth increased. Banting (1979) found that germination of *H. jubatum* was greatest when temperatures fluctuated. In addition, results from Banting (1979) also found that light, especially continuous light at constant temperatures reduced germination of *H. jubatum*. Germination and viability of *H.*

jubatum seed has been found to decline significantly over time after burial in the soil (Badger and Ungar 1994; Banting 1979; Conn and Deck 1995; Donald 1990).

Khan and Gulzar (2003) note that germination of grass species, such as *H. jubatum*, is successful due to their ability to adapt to seasonal changes when moisture and salinity levels are favorable for germination to occur. Generally, germination of *H. jubatum* occurs from late August to September as well as the following spring when environmental conditions are favorable (Best et al. 1978). Under desirable environmental conditions, *H. jubatum* seed germination can be as high as 98% and seed that does not germinate in the fall can germinate in the spring (Badger and Ungar 1989). *H. jubatum* is considered to have a variant of a Type III persistent seed bank (Thompson and Grime 1979), allowing it to have biannual germination with a conditional dormancy (Badger and Ungar 1994; Baskin and Baskin 1989). Boyd and Van Acker (2004) demonstrated that seed germination progressively decreased with lower osmotic potentials. Under hypersaline conditions halophyte seeds can remain in enforced dormancy for up to two years and then germinate if the salinity stress is alleviated (Keiffer and Ungar 1997; Ungar 2001). However, seed longevity and viability of *H. jubatum* was found to be less when compared with other wetland plant species (Banting 1979; Leck 1989). Germination studies performed by Cords (1960) suggest that *H. jubatum* seed from the current season is the major source of reestablishment and infestation, while seed that remains in the soil and overwinters loses much of its viability. Additional studies supporting Cords (1960) conclusions have also observed that *H. jubatum* seed is non-persistent in the soil (Banting 1979; Chepil 1946; Conn and Farris 1987).

Seed Bank

Dormancy mechanisms allow seeds to survive in the soil seed bank and germinate when conditions are favorable to plant establishment (Ghersa and Roush 1993). Ungar (1991) found that seed banks of *Hordeum jubatum* are important for maintaining plant populations in inland saline marshes. A single *H. jubatum* plant is capable of yielding over 180 seeds with 67% of the seeds remaining viable in the soil for 1 year (Conn and Deck 1995). Results from Banting (1979), state that *H. jubatum* seeds which remain on the soil surface experience a higher loss of seed viability. Furthermore, Banting (1979) maintains that some buried *H. jubatum* seeds were still viable after 7 years. Additionally, Conn and Deck (1995) determined that the viability of *H. jubatum* seed was less than 1% after 3.7 years; however, in agreement with Banting (1979), they concluded that more than 6.7 years are required to reduce *H. jubatum* seed viability completely. Badger and Ungar (1990) found that an increase in salinity resulted in decreased seed production and a reduction of mature plants that were capable of reproducing. In 1994, Badger and Ungar concluded from their research in a Rittman, Ohio marsh that a relatively small persistent seed bank permits *H. jubatum* to maintain a population due to multiple germination opportunities in the unpredictable salt marsh habitat.

The presence or absence of aboveground vegetation does not necessarily associate or determine the amount and density of a species seed bank within the soil (Smith and Kadlec 1983; Ungar 2001). Investigations done by Ungar and Riehl (1980) report that seed banks of inland saline marshes are strongly representative of the current vegetation. In contrast, research done by Smith and Kadlec (1983) found that *H. jubatum* was present in the field but was absent in seed bank samples. Conn (1987; 2006) found that seed density in the seed bank accumulated in no-till and reduced tillage operations resulting in increased *H. jubatum* populations. This information helps explain why *H. jubatum* can become problematic in pasture settings.

Management and Control

The management and control of *Hordeum jubatum* can be difficult due to the location and field conditions in which it is found. Infestations of *H. jubatum* often occur in areas that are unsuitable for cultivation and in pastures with low productivity (Dodd and Coupland 1966). As such, *H. jubatum* has become a troublesome weed that contaminates irrigated pastures, hayfields, and other desirable crops causing reduced yields and poor quality crops (Blouch 1953; Moyer and Boswall 2002). Areas that experience seasonal flooding make it complicated for land owners to get equipment onto infested areas to treat and manage populations of *H. jubatum* efficiently. A practical and effective control method is necessary for the improvement of areas infested with *H. jubatum*. Some techniques or methods that have been attempted to effectively manage and control *H. jubatum* include grazing, mowing, increased drainage, reseeding, burning, tillage, forage/crop competition, and herbicides. Under different circumstances each method has produced variable results.

Grazing and Mowing

Grazing and mowing can suppress seed head production. However, it has been observed that *Hordeum jubatum* will produce seed heads closer to the ground making it more resistant to mower blades (Mike Wangsgaard personal observation). Best et al. (1978) suggests that *H. jubatum* should be mowed within 10 days after seed heads emerge to prevent the formation of viable seeds; noting however, that repeated or successive mowing can improve the competitive ability of *H. jubatum*. Additionally, Best et al. (1978) claim *H. jubatum* is capable of generating viable seeds if mowing does not occur within 10 days of seed head emergence, although germination may be reduced.

Early vegetative growth is palatable and nutritious for grazing livestock until seed heads are formed at which time livestock tend to avoid grazing *H. jubatum* as it matures (Bowes 1984; White 1984). When grazed in early spring by sheep or cattle, Muenscher (1955) noticed that *H. jubatum* was setback severely. When seed heads develop and mature, stiff awns can become embedded into the mouth, eyes, ears, and skin of grazing animals causing injury, irritation, and infection (Blouch 1953; Bowes 1984; Cords 1960; White 1984). Overgrazing or preferential grazing promotes the establishment of *H. jubatum* by reducing and suppressing the competitive ability of desirable grasses and other vegetation (Bowes 1984; Moyer and Boswall 2002; White 1984).

Drainage and Reseeding

Increasing soil drainage and diverting spring runoff in drawdown areas is extremely intensive and difficult to maintain. Altering existing terrain and contours can result in extensive disturbances to the landscape and can lead to negative outcomes later on. Often this method is not an economical option, due to the cost and effort that is required. Cords (1960) and Best et al. (1978) indicate that draining an area without introducing or reseeding desirable vegetation will often result in an increased *Hordeum jubatum* population instead of a desired reduction.

Burning

Burning has been found to both suppress and enhance populations of *Hordeum jubatum*. *H. jubatum* is an invader of disturbed areas; often one of the first grasses to become established after a disturbance occurs (Eichorn and Watts 1984; Millar 1973). Burning *H. jubatum* may be beneficial for removing aboveground growth, but it is difficult to generate enough heat to damage the root system due to the insulating and buffering capacity of the soil. Off-site seed sources allow *H. jubatum* to recover and establish quickly (Hansen et al. 1988). *H. jubatum* was greatly reduced following a prairie fire in North Dakota (Hadley 1970). However, following a burn in Montana, *H. jubatum* growth was stimulated, causing it to become one of the first grasses to establish on the disturbed site (Eichorn and Watts 1984). It has been suggested that burning is most effective in the spring when *H. jubatum* is actively growing (Wright and Bailey 1982; Young 1986).

Tillage

Hordeum jubatum can easily be controlled by tillage due to its shallow root system. Conn (2006) suggested tillage affected the seed bank of *H. jubatum* significantly. Donald (1990) along with Wrucke and Arnold (1985) state that *H. jubatum* establishment is best adapted to no-till land and often increases in abundance (Derksen et al. 2002). This results from the ability of *H. jubatum* to germinate on the soil surface, thus allowing it to establish effectively on no-till land (Banting 1979; Hoffman et al. 1980). When tillage was discontinued in wheat production McConkey and Peru (1995) observed that *H. jubatum* became a serious problem within 2 to 4 years. Conn (1987;

2006) also claims that *H. jubatum* populations increased significantly in no-till and reduced tillage operations, but also found that a minimum amount of tillage (one spring disking) reduced total weed cover by half. Wicks and Somerhalder (1971) note that reduced tillage permits greater weed pressure by allowing weed seed concentrations to accumulate on the soil surface. Deep tillage with moldboard or chisel plowing effectively killed established *H. jubatum* plants and prevented seedling establishment by burying seed too deeply for successful emergence to occur (Donald 1990). Tillage and reseeding in a pasture setting may be a control option but additional problems can arise if *H. jubatum* reestablishes with the new grass stand. Reseeding areas favorable to *H. jubatum* establishment with desirable grasses may have limited success if *H. jubatum* cannot be selectively controlled.

Forage and Crop Competition

The establishment and control of *Hordeum jubatum* depends largely on how well competitive and adaptive plant species compete for space and nutrients (Best et al. 1978; Cords 1960; Whitson and Koch 1998). Of the grass species Moyer and Boswall (2002) studied, they concluded that tall fescue and creeping foxtail were the most competitive and adaptive species that suppressed *H. jubatum* growth and establishment. Greenhouse experiments completed by Wilson (1967) compared moisture and salinity differences between *H. jubatum* and desirable grasses (reed canarygrass, tall fescue, and tall wheatgrass). In wet, non-saline soil Wilson (1967) reported a reduction in *H. jubatum* yield; while orchardgrass provided intense competition. In wet, saline soil Wilson (1967) noted that *H. jubatum* was suppressed most by tall wheatgrass, with tall fescue and reed canarygrass also providing good growth suppression. Whitson et al. (1999) found that

'Jose' tall wheatgrass and Newhy hybrid wheatgrass suppressed *H. jubatum* growth by 57 and 47%, respectively. Competition from invading *Poa* spp. suppressed *H. jubatum* by 75 percent during a one year period (Best et al. 1978). Understanding the tolerances and adaptability of desirable grass species to salinity, flooding, and herbicides will allow landowners to implement and utilize an integrated approach for the management and control of *H. jubatum*.

Herbicides

Chemical control of *Hordeum jubatum* with the use of herbicides is another alternative for *H. jubatum* management and control. However, Best et al. (1978) and Blackshaw et al. (1998) indicate there are no selective herbicides recommended for *H. jubatum* control. Donald (1988) determined that glyphosate can effectively control *H. jubatum* when applied prior to planting a small grain crop. McConkey and Peru (1995) claim that glyphosate provides good control of established *H. jubatum* plants in some years but in other years when *H. jubatum* is stressed, it is difficult to control even at higher rates. Being a non-selective herbicide, glyphosate is detrimental to desirable grasses if applied in a pasture setting. Propyzamide treatments applied in early and late fall effectively controlled *H. jubatum* for at least 2 years; however, *H. jubatum* completely reinvaded the treated sites within 5 years (Bowes 1984). Some herbicides, when applied at a specific rate, may selectively control *H. jubatum* while causing only minor injury or stress to desirable grasses. Hamman and Wilson (1977) selectively controlled *H. jubatum* by 85 to 96% in pastures with a fall application of pronamide, but failed to control *H. jubatum* with a spring application. They also observed that established stands of orchardgrass and bromegrass were injured only slightly. However, Moyer and Boswall (2002) claim that attempts from the past 20 to 30 years have not yielded herbicide treatments that will control *H. jubatum* effectively in grass pastures. Bowes (1984) reported that eradication of *H. jubatum* with propyzamide alone is impossible due to the fact that following the highest application rate a few single plants remained. Determining herbicides that can effectively and selectivity control *H. jubatum* without severely injuring desirable grasses will provide an excellent control option against *H. jubatum*.

Objectives

The objectives of this research are outlined as follows:

1) Determine the herbicide dose response of *Hordeum jubatum* and six desirable grass species to postemergent herbicide applications.
2) Compare the salinity tolerance of *Hordeum jubatum* and seven desirable grass species to increasing electrical conductivities (EC) over time.
3) Assess the response of *Hordeum jubatum* and six desirable grass species to different durations of flooding.

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CHAPTER 2

HERBICIDE TOLERANCE OF FOXTAIL BARLEY (*Hordeum jubatum* L.) AND DESIRABLE PASTURE GRASSES

Abstract

Selective control of foxtail barley (*Hordeum jubatum*) from within pasture grasses can be useful in an integrated weed management program. A greenhouse study was conducted to determine the tolerance of foxtail barley and six pasture grass species to four herbicides. Grass species included in the study were 'Palaton' reed canarygrass (*Phalaris arundinacea*), 'Climax' timothy (*Phleum pratense*), 'Mustang' altai wildrye (*Leymus angustus*), 'Fawn' tall fescue (*Festuca arundinaceae*), 'Alkar' tall wheatgrass (*Thinopyrum ponticum*), 'Potomac' orchardgrass (*Dactylis glomerata*), 'Garrison' creeping foxtail (*Alopecurus arundinaceus*), and foxtail barley. Herbicides evaluated in the study were imazapic, propoxycarbazone, sulfosulfuron, and flucarbazone at rates of 0, 10, 25, 50, 100, and 200 g ha^{-1}. Herbicide tolerance differed significantly among grass species. Creeping foxtail and reed canarygrass were highly susceptible to all herbicides tested in both runs. Foxtail barley and timothy showed moderate tolerance to flucarbazone in both runs, while tall fescue only showed tolerance to flucarbazone in run two. Tall wheatgrass was extremely tolerant to flucarbazone with EC_{50} values beyond the maximum rate evaluated (200 g ha^{-1}) in both runs. At the rates evaluated, applications of propoxycarbazone and sulfosulfuron were most effective against foxtail barley resulting in low EC_{50} values in both runs. Orchardgrass exhibited tolerance to propoxycarbazone with EC_{50} values of 113 and 74 g ha^{-1} in run one and two, respectively. Propoxycarbazone may have potential to selectively control foxtail barley

from within orchardgrass and should be further investigated in field studies. With the exception of orchardgrass tolerance to propoxycarbazone, there appears to be little possibility for selective removal of foxtail barley from the grasses evaluated using postemergent ALS herbicide applications.

Introduction

Foxtail barley (*Hordeum jubatum* L.) is a native, cool-season, short-lived perennial bunchgrass that grows prevalently throughout most of North America (Badger and Ungar 1990; Best et al. 1978; Cords 1960). Most commonly foxtail barley is found growing in meadows, prairies, and pastures where saline depressions and seasonal flooding generally occur (Badger and Ungar 1990; Best et al. 1978; Cords 1960; Whitson et al. 2000). Foxtail barley matures to a height of 0.3 to 0.6 m tall, has a distinctive bluish to grayish-green leaf color, and produces characteristic nodding seed heads (Best et al. 1978; Whitson et al. 2000). Prolific seed production and high germination rates enable foxtail barley to replenish seed bank reserves and establish and persist in saline environments where other vegetation struggles to compete (Badger and Ungar 1989; Boyd and Van Acker 2003). Foxtail barley expresses a variant of a Type III persistent seed bank (Thompson and Grime 1979) which allows some seed to germinate soon after release while others persist longer in the soil (Badger and Ungar 1994). This type of seed dormancy permits seed that does not germinate in the fall to germinate in the spring when environmental conditions experienced in the soil are alleviated and favorable to germination (Badger and Ungar 1994; Baskin and Baskin 1989; Best et al. 1978; Khan and Gulzar 2003). At maturity, seed heads of foxtail barley cause detrimental injury to grazing livestock and significantly reduce forage quality (Blouch 1953; Bowes 1984;

Cords 1960; White 1984). Due to poor palatability and injury caused by foxtail barley at maturity, livestock preferentially graze or overgraze desirable grass species, thereby suppressing the competitive ability of desirable grasses and promoting the establishment of foxtail barley (Bowes 1984; Moyer and Boswall 2002). Control methods for foxtail barley such as tillage, mowing, burning, and crop competition have had variable success; however, the integration of herbicides could significantly improve the efficiency and effectiveness of these methods.

Herbicides offer a wide variety of management possibilities when an integrated approach is used to control foxtail barley. The utilization and incorporation of multiple control strategies in an integrated weed management program greatly improves the control potential better than one strategy alone (Derksen et al. 2002). Control of foxtail barley is often more successful when herbicides (Blackshaw et al. 1998; Bowes 1984; Cords 1956; Donald 1988; Hamman and Wilson 1977; Violett et al. 2007) are combined with other factors such as competition from other vegetation (Cords 1958; Moyer and Boswall 2002; Whitson and Langbehn 2000).

Sensitivity and tolerance to herbicides can vary depending on the rate at which the herbicide is applied as well as the time of application (Johnson and Carrow 1995). Recommended use rates of specific herbicides may effectively control specific species; however, it is possible to observe herbicide tolerance with lower use rates. However, an injury allowance must be accepted when lower rates are used on species which are otherwise susceptible to a specific herbicide.

The ability to selectively remove undesirable species from within desirable species with the use of herbicides provides a useful control option. Herbicide applications can be extremely beneficial in an integrated weed management program if undesirable species, such as foxtail barley, are effectively controlled while inflicting only minor injury to desirable species. However, desirable species are not benefitted when herbicide applications severely injury or control both desirable and undesirable species. Herbicides which allow desirable species to recover and persist satisfactorily from minor injury while controlling the undesirable species provide a useful tool for integrated weed management programs.

Numerous tolerance studies have been carried out to evaluate plant injury and response to herbicides, application rates, growth stages at application, and application timing (Brewster and Spinney 1989; Canode and Robocker 1969; Comes et al. 1981; Kerr 1968; McCarty et al. 1989; Monaco and Creech 2004; Peters et al. 1989; Sheley 2007; Shinn and Thill 2004; Warren et al. 1989; Wilson 1995). Donald (1988) determined that glyphosate effectively controlled *H. jubatum* when applied prior to planting a small grain crop. McConkey and Peru (1995) claim that glyphosate provides good control of established *H. jubatum* plants in some years, but in other years when *H. jubatum* is stressed, it is difficult to control even at higher application rates. Propyzamide treatments applied in early and late fall effectively controlled *H. jubatum* for at least 2 years; however, *H. jubatum* completely reinvaded the treated sites within 5 years (Bowes 1984). Hamman and Wilson (1977) selectively controlled *H. jubatum* in a pasture by 85 to 96% with a fall application of pronamide, but failed to control *H. jubatum* with a spring application. However, with reports of successful foxtail barley control, Moyer and Boswall (2002) claim that attempts from the past 20 to 30 years have not yielded herbicide treatments that will control *H. jubatum* effectively in grass pastures. Bowes

(1984) reported that eradication of *H. jubatum* with propyzamide alone is impossible due to the fact that following the highest application rate some individual *H. jubatum* plants remained.

Herbicides have been used in attempts to suppress seedhead production of grasses (Canode 1974; Canode et al. 1962; Elkins 1974; Elkins et al. 1974; White 1989). White (1984) indicated that herbicides can suppress foxtail barley seedhead production which could allow foxtail barley to be grazed without injuring livestock. In addition to providing the option for livestock to graze foxtail barley, seedhead suppression reduces rejuvenation of the soil seed bank which is a vital component to foxtail barley's reestablishment potential (Badger and Ungar 1994; Ungar 2001).

Although certain herbicides have been shown to provide control and suppress seedhead production of foxtail barley, often foxtail barley is only controlled for short intervals before it becomes reestablished (Bowes 1984). Nonselective herbicides can control foxtail barley, but desirable vegetation is also removed which creates conditions that are favorable for the reinvasion and reestablishment of foxtail barley.

This study was conducted to determine the tolerance of foxtail barley and six desirable grasses to four ALS herbicides. Limited references exist on selective control of undesirable grasses from desirable grasses (Lee 1965). The purpose of determining the tolerance of each grass species to each herbicide was to determine if foxtail barley can be selectively controlled without severely injuring the desirable grasses. By allowing desirable grasses to remain, foxtail barley will need to compete with other vegetation in order to reestablish. Based on the tolerance of each grass species, the most tolerant grasses can be selected to allow the potential ability to selectively remove foxtail barley from within those grasses.

Methods and Materials

Herbicide tolerance of foxtail barley and six pasture grasses was studied at the Utah State University research greenhouse in Logan, Utah. Grass seed of ‘Garrison’ creeping foxtail (*Alopecurus arundinaceus*), ‘Potomac’ orchardgrass (*Dactylis glomerata*), ‘Palaton’ reed canarygrass (*Phalaris arundinacea*), ‘Fawn’ tall fescue (*Festuca arundinaceae*), ‘Alkar’ tall wheatgrass (*Thinopyrum ponticum*), and ‘Climax’ timothy (*Phleum pratense*) was obtained from Wheatland Seed Inc. in Brigham City, Utah. Foxtail barley (*Hordeum jubatum*) seed was collected from an established infestation located in Cache Junction, Utah. Grasses were planted individually into cone-tainers[1] filled with a mixture of peatmoss and vermiculite. Plants were hand watered daily with tap water until seedlings emerged. Grasses were cut to a uniform height of 6 cm, 6 weeks after planting and allowed to regrow for 2 weeks before herbicides were applied. Herbicide treatments were applied 8 weeks after grasses were planted. Herbicides were applied in an enclosed research track sprayer with an 8002 flat fan nozzle calibrated to deliver 187 L ha^{-1} at 207 kPa. The herbicides used were, imazapic, propoxycarbazone, sulfosulfuron, and flucarbazone applied at rates of 0, 10, 25, 50, 100, and 200 g ha^{-1}. The study was conducted as a completely randomized design with four replications and completed twice. Each herbicide treatment consisted of seven individual plants per replication. Four weeks after treatments visual injury was assessed, height was measured, and biomass was harvested (6 cm aboveground). Grasses were allowed to regrow for 2 weeks at which time height was measured and biomass regrowth (6 cm aboveground) was harvested. Biomass samples were oven dried and weighed.

General model significance was determined using ANOVA. Data from run one and two was not combined due to significant run-by-species-by-herbicide interactions. These differences most likely occurred as a result of species responses to differing environmental factors between runs (Ritz et al. 2006). Due to non-homogeneous variances, data was transformed, however, transformations did not change or improve the data therefore the actual biomass production values were used for analysis. Data were fit to a 3-parameter logistic dose-response model (Equation 1) as shown below:

$$\mathrm{Y} = a/1 + (x/x_o)^b \qquad [1]$$

where x_o represents the EC_{50} value (the rate reducing biomass by 50%) and x represents a given herbicide rate. The upper limit is denoted by a, and parameter b indicates the relative slope around the EC_{50} value. The 3-parameter logistic dose-response model was used to fix data at the lower limits of the curve to zero, thereby preventing the occurrence of misleading data due to the estimation of data points at the lower limits of the curve (Knezevic et al. 2007). EC_{50} values were derived using the raw biomass data (Knezevic et al. 2007). Although parameter estimates of the dose-response curves were determined using actual biomass production data, the relative percentage of biomass production was used for the graphical representation[2] of the data displayed in Figures 2-1 and 2-2 (Knezevic et al. 2007; Seefeldt et al. 1995). Some grass species exhibited hormesis at lower herbicide rates (Cedergreen 2008; Knezevic et al. 2007; Seefeldt et al. 1995;

Schabenberger et al. 1999). However, dose-response models that account for hormesis did not significantly improve the fit of the data, therefore, for simplicity and comparison reasons all dose-response curves were fit using the 3-parameter logistic dose-response model.

Results and Discussion

Herbicide tolerance varied significantly among all grass species and herbicides. In both runs creeping foxtail and reed canarygrass appeared to be most susceptible to all herbicide treatments. Orchardgrass, tall fescue, and timothy demonstrated high levels of variation between runs, which is likely due to environmental differences experienced in the greenhouse. Foxtail barley and tall wheatgrass exhibited the most consistent results between both runs. Foxtail barley was most sensitive to propoxycarbazone (EC_{50} = 5 and 8 g ha^{-1}) and sulfosulfuron (EC_{50} = 14 and 6 g ha^{-1}) in run one and two, respectively. Imazapic (EC_{50} = 29 and 29 g ha^{-1}) and flucarbazone (EC_{50} = 28 and 35 g ha^{-1}) required higher doses in run one and two, respectively, to reduce biomass production of foxtail barley by 50% (Table 2-1).

Tall wheatgrass exhibited extremely high tolerance to flucarbazone with EC_{50} values >200 g ha^{-1} in both runs. Timothy was also very tolerant of flucarbazone with EC_{50} values of 78 and >200 g ha^{-1} in run one and two, respectively. Orchardgrass displayed a high tolerance to propoxycarbazone in run one with an EC_{50} value of 113 g ha^{-1}. However, in run two orchardgrass exhibited a higher tolerance to imazapic with an EC_{50} value of 107 g ha^{-1} while propoxycarbazone tolerance was reduced to an EC_{50} value of 73 g ha^{-1} (Table 2-1).

When EC_{50} values are compared to the actual recommended use rates of each herbicide, few opportunities for selective control of foxtail barley from within desirable grass stands were apparent. Recommended use rates for imazapic range from 140-210 g ha^{-1} (Anonymous 2008b). Data shows that all the desirable grasses treated with imazapic would be controlled or injured as much or more than foxtail barley when used at the recommended use rates (Table 2-1).

Propoxycarbazone has recommended use rates between 29-44 g ha^{-1} (Anonymous 2006a). At these rates the majority of the desirable grass species tested would be severely injured. Timothy and tall fescue were susceptible to propoxycarbazone (EC_{50} = 24 and 8 g ha^{-1}, respectively) in run one; however, in run two these grass species exhibited higher EC_{50} values of 61 and 54 g ha^{-1}, respectively. Orchardgrass displayed a high tolerance to propoxycarbazone in both runs with EC_{50} values of 113 and 73 g ha^{-1}, respectively. Selective control of foxtail barley from within orchardgrass appears to be an option with applications of propoxycarbazone. It is interesting to note that in run one and two the EC_{50} values of orchardgrass (113 and 73 g ha^{-1}, respectively) are significantly higher than the EC_{50} values of foxtail barley (5 and 8 g ha^{-1}, respectively) which suggests that foxtail barley potentially could be selectively controlled with propoxycarbazone in stands of orchardgrass (Table 2-1).

All tested grass species experienced significant injury and biomass reductions with applications of sulfosulfuron. Use rates recommended for sulfosulfuron fluctuate from 39-105 g ha^{-1} (Anonymous 2006b). Extreme biomass reduction and injury to all the tested grass species will result at these rates with applications of sulfosulfuron. With such high activity, sulfosulfuron does not show any selectivity potential among the tested grass species (Figures 2-1 and 2-2).

Flucarbazone has a recommended use rate of 29 g ha^{-1} (Anonymous 2008a). Overall, flucarbazone appeared to be the least active herbicide on many of the grass species tested. Although grass tolerance to flucarbazone was fairly high in run one it was much higher in run two. The high tolerance to flucarbazone displayed by tall wheatgrass and timothy allow the potential to selectively control undesirable species from within stands of tall wheatgrass or timothy. However, selectively controlling foxtail barley within these species appears unlikely, due to the fact that foxtail barley was also fairly tolerant of flucarbazone applications with EC_{50} values of 28 and 35 g ha^{-1} in run one and two, respectively (Table 2-1).

Although some grass species displayed tolerance to the tested herbicides in greenhouse trials, further testing must be conducted in field trials to substantiate the conclusions obtained in the greenhouse. Land managers interested in selective control of undesirable species, such as foxtail barley, must be aware of potential injury to desirable plant species. All forage grasses tested by Peters et al. (1989) were injured to some extent by registered herbicide applications, suggesting that injury allowances need to be considered before herbicide treatments are applied. Further investigation in field trials will provide more conclusive results which can assist land managers in determining potential injury that may occur to desirable species as a result of herbicide applications. It is important to note that no benefit to an integrated weed management approach is accomplished when desirable species experience significant injury, reduced seed production, and are unable to recover and adequately persist after herbicide applications.

Peters et al. (1989) advocate that herbicides which control grass weeds, but severely injure forage grasses are not useful. Herbicide applications which create space due to the removal of desirable vegetation increase the reestablishment potential of undesirable species such as foxtail barley.

Additional factors that need further consideration in field trials are herbicide susceptibility at various plant growth stages, herbicide application timing (Blackshaw et al. 1998; Johnson and Murphy 1991), and establishment of desirable species. Dormant herbicide applications have been shown to provide significantly different results from postemergent herbicide applications (Bowes 1984; Brewster and Spinney 1989; Hamman and Wilson 1977). Seedling germination and establishment may be influenced dramatically by herbicide applications while established plants may be more tolerant due to more extensive root systems (Blackshaw et al. 1999; Comes et al. 1981). Reduced seed production has been observed in previous studies which could significantly alter the life cycle of undesirable species such as foxtail barley (Elkins and Suttner 1974; Reynolds et al. 1993; Whitson et al. 1997).

Successfully establishing desirable grass species in adverse environments is an essential challenge that needs to be addressed. Although a specific grass species may demonstrate herbicide tolerance, selective control of foxtail barley is not possible if desirable grass species are unable to successfully establish and compete in the adverse environments where foxtail barley is found. However, if desirable grass species show tolerance to herbicides and can become established in these adverse environments then selective herbicide applications can further increase the competitive ability of desirable grass species while debilitating foxtail barley.

Sources of Materials

[1]Cone-tainers, Stuewe and Sons Inc., 2290 SE Kiger Island Drive Corvallis, Oregon 97333-9425.

[2]SigmaPlot 9.0, SigmaPlot 2004 for Windows, Version 0.1, SYSTAT Software Inc., 501 Conal Blvd, Suite C. Point Richmond, CA 94804-2028.

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Table 2-1. Parameter estimates for 3-parameter dose-response curves describing grass response to herbicides (Equation 1).[a]

Species	Herbicide[b]	EC_{50}		a		b		R^2	
		Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
		——— $g\ ha^{-1}$ ———							
Foxtail barley	Imazapic	29.20 (10.69)	29.02 (6.51)	4.62 (0.73)	3.85 (0.31)	1.78 (0.91)	1.28 (0.29)	0.90	0.97
	Propoxy.	5.00 (1.56)	8.14 (0.36)	4.22 (0.17)	3.96 (0.06)	1.50 (0.49)	1.73 (0.13)	0.99	1.00
	Sulfo.	14.40 (1.03)	6.12 (0.40)	4.23 (0.15)	3.97 (0.05)	2.24 (0.27)	1.46 (0.11)	1.00	1.00
	Flucarb.	28.47 (5.69)	35.00 (5.33)	4.19 (0.19)	4.01 (0.17)	0.68 (0.10)	0.91 (0.11)	0.99	0.99
Creeping foxtail	Imazapic	6.88 (0.96)	14.89 (4.38)	2.82 (0.09)	5.95 (0.65)	1.72 (0.36)	1.42 (0.49)	1.00	0.95
	Propoxy.	1.44 (0.75)	4.96 (4.40)	2.82 (0.05)	5.87 (0.54)	0.86 (0.19)	0.58 (0.26)	1.00	0.95
	Sulfo.	7.58 (0.36)	0.12 (0.51)	2.82 (0.04)	5.86 (0.38)	2.53 (0.33)	0.24 (0.18)	1.00	0.98
	Flucarb.	2.74 (0.55)	33.44 (7.39)	2.82 (0.07)	5.94 (0.42)	0.79 (0.12)	1.09 (0.22)	1.00	0.97
Orchardgrass	Imazapic	21.27 (5.98)	107.37 (19.56)	5.73 (0.74)	5.51 (0.45)	1.96 (0.82)	2.88 (1.41)	0.93	0.92
	Propoxy.	113.3 (22.95)	73.52 (25.52)	5.63 (0.40)	6.34 (0.44)	1.48 (0.47)	0.60 (0.16)	0.94	0.95
	Sulfo.	32.76 (5.26)	22.44 (4.72)	5.40 (0.26)	6.34 (0.44)	1.00 (0.14)	1.15 (0.23)	0.99	0.98
	Flucarb.	9.41 (1.83)	45.15 (41.11)	5.44 (0.19)	6.32 (1.03)	0.76 (0.10)	0.51 (0.33)	0.99	0.80
Reed canarygrass	Imazapic	6.61 (0.93)	4.47 (4.46)	6.44 (0.20)	2.29 (0.20)	1.63 (0.32)	0.49 (0.22)	1.00	0.96
	Propoxy.	4.25 (0.45)	1.68 (3.26)	6.44 (0.07)	2.29 (0.19)	0.79 (0.05)	0.32 (0.19)	1.00	0.96
	Sulfo.	14.92 (2.11)	3.90 (2.28)	6.50 (0.45)	2.29 (0.13)	2.12 (0.47)	0.65 (0.19)	0.98	0.98
	Flucarb.	9.51 (2.42)	16.66 (10.83)	6.46 (0.43)	2.25 (0.36)	1.14 (0.28)	0.85 (0.43)	0.98	0.88
Timothy	Imazapic	9.80 (7.14)	11.96 (7.67)	5.72 (0.07)	5.12 (0.70)	24.01 (4.02)	0.80 (0.38)	1.00	0.92
	Propoxy.	24.58 (7.41)	61.00 (11.18)	5.73 (0.56)	6.08 (0.59)	1.13 (0.32)	3.57 (1.91)	0.95	0.92
	Sulfo.	8.19 (2.31)	26.39 (3.95)	5.70 (0.29)	5.12 (0.26)	0.81 (0.16)	1.18 (0.17)	0.99	0.99
	Flucarb.	78.24 (43.65)	>200	5.71 (0.86)	—	0.88 (0.46)	—	0.83	—
Tall fescue	Imazapic	0.70 (0.40)	1.44 (1.77)	4.22 (0.07)	2.71 (0.16)	0.62 (0.11)	0.59 (0.26)	1.00	0.99
	Propoxy.	7.94 (2.07)	54.31 (28.86)	4.22 (0.14)	2.82 (0.56)	0.55 (0.08)	1.45 (0.95)	0.99	0.78
	Sulfo.	17.38 (3.12)	20.75 (42.53)	4.27 (0.28)	2.95 (0.59)	1.32 (0.25)	7.71 (83.78)	0.98	0.88
	Flucarb.	16.94 (4.10)	138.34 (32.03)	4.25 (0.30)	3.21 (0.29)	1.01 (0.21)	2.31 (1.24)	0.98	0.86
Tall wheatgrass	Imazapic	25.59 (2.03)	57.39 (13.38)	4.47 (0.22)	2.94 (0.24)	3.32 (0.92)	1.35 (0.37)	0.99	0.95
	Propoxy.	14.73 (2.83)	13.10 (0.72)	4.24 (0.35)	2.77 (0.05)	1.73 (0.46)	1.31 (0.08)	0.97	1.00
	Sulfo.	23.48 (2.90)	33.78 (4.15)	4.36 (0.26)	2.73 (0.12)	2.16 (0.45)	1.22 (0.15)	0.99	0.99
	Flucarb.	>200	>200	—	—	—	—	—	—

[a]Data values followed by standard errors in parentheses. Parameter estimates based from actual biomass data.

[b]Abbreviations: Propoxy., Propoxycarbazone; Sulfo., Sulfosulfuron; Flucarb., Flucarbazone.

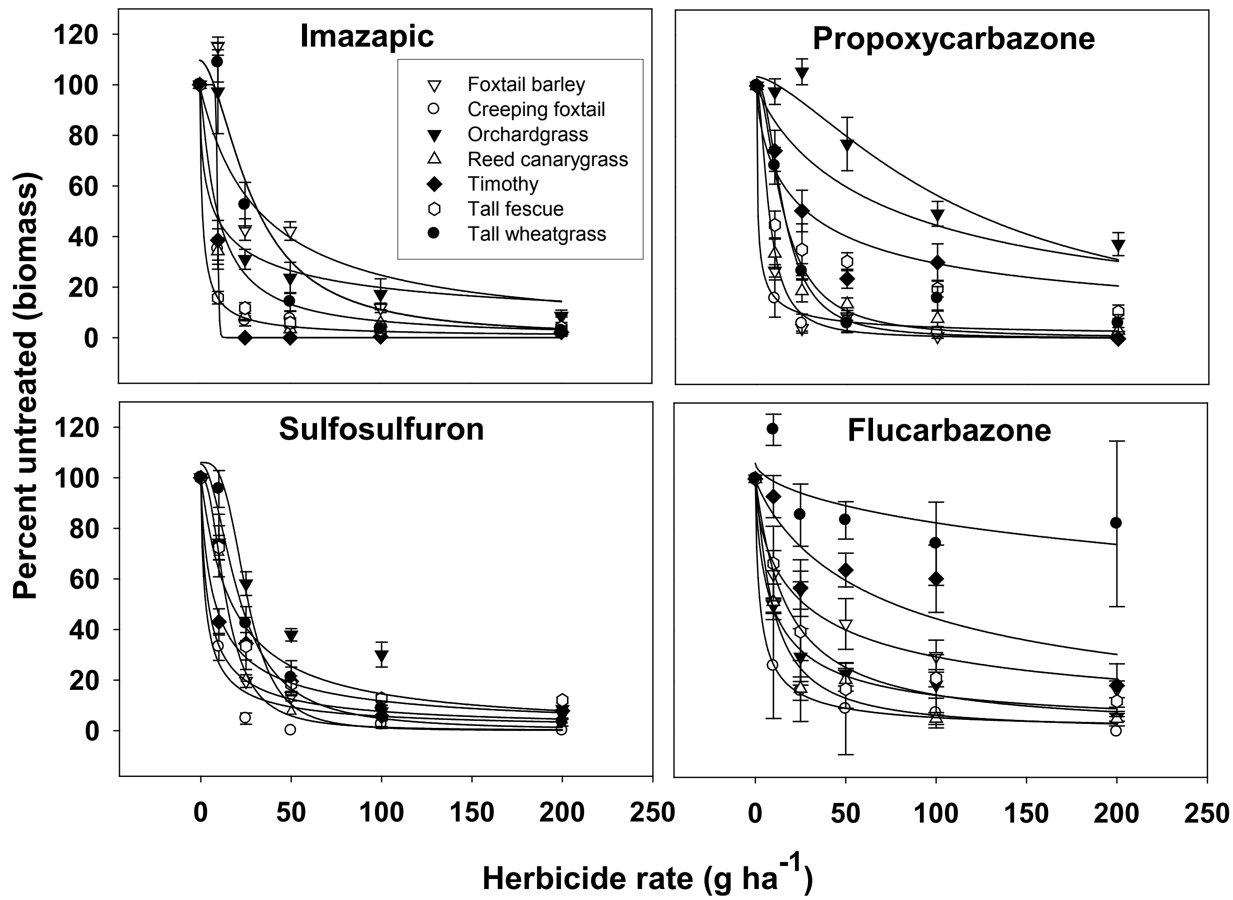

Figure 2-1. Foxtail barley and pasture grass species response to increasing herbicide rates in greenhouse trials (Run 1). Data fit to a 3-parameter logistic curve and parameter estimates are presented in Table 2-1.

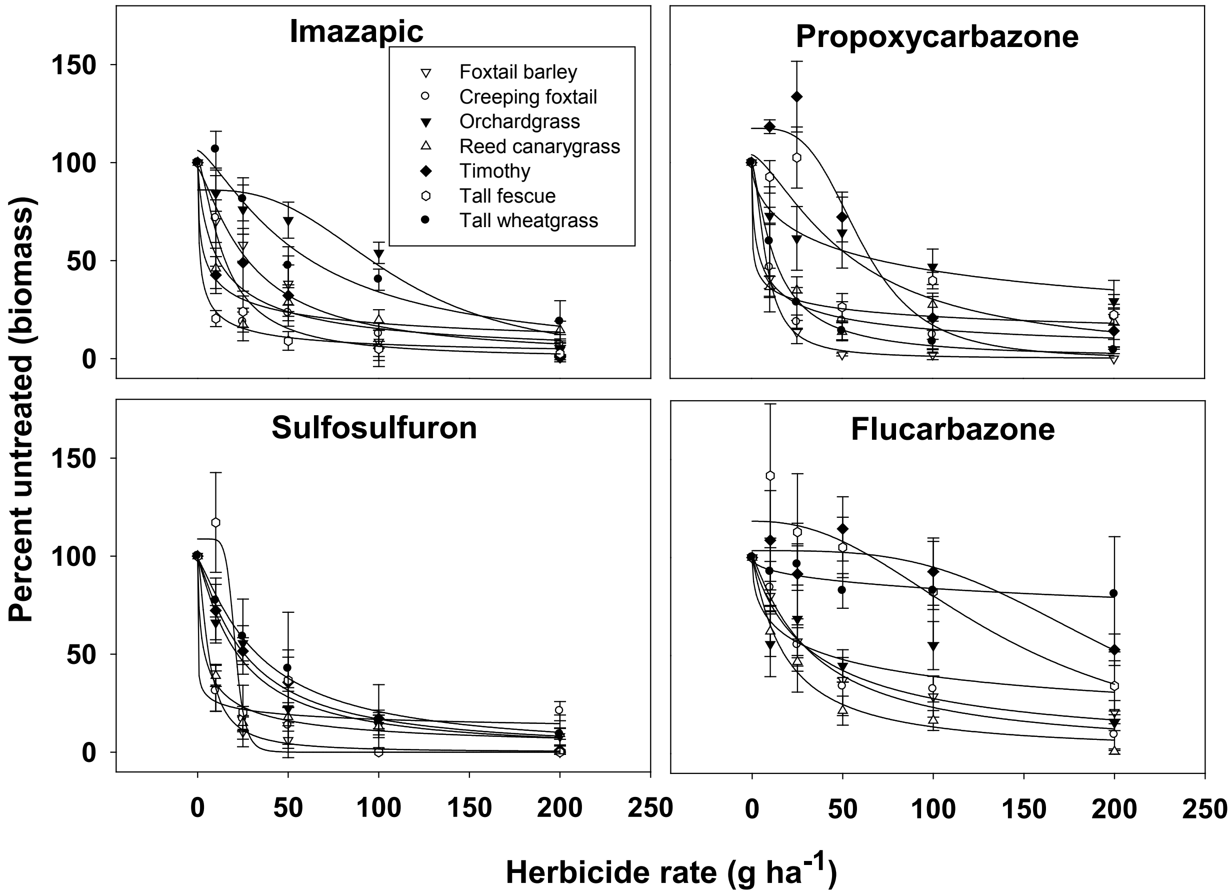

Figure 2-2. Foxtail barley and pasture grass species response to increasing herbicide rates in greenhouse trials (Run 2). Data fit to a 3-parameter logistic curve and parameter estimates are presented in Table 2-1.

CHAPTER 3

SALINITY TOLERANCE OF FOXTAIL BARLEY (*Hordeum jubatum* L.) AND DESIRABLE PASTURE GRASSES

Abstract

A greenhouse study was conducted to determine the relative salinity tolerance of foxtail barley and seven desirable pasture grasses. Grass species included in the study were 'Palaton' reed canarygrass (*Phalaris arundinacea*), 'Climax' timothy (*Phleum pratense*), 'Mustang' altai wildrye (*Leymus angustus*), 'Fawn' tall fescue (*Festuca arundinaceae*), 'Alkar' tall wheatgrass (*Thinopyrum ponticum*), 'Potomac' orchardgrass (*Dactylis glomerata*), 'Garrison' creeping foxtail (*Alopecurus arundinaceus*), and foxtail barley (*Hordeum jubatum*). Grasses were exposed to increasing EC levels of NaCl and $CaCl_2$ salt solution over time. Grass species were compared using a cumulative value of salt exposure (ECdays) which was calculated to account for the EC and the time and a plant was exposed at that level of conductivity. Salinity tolerance varied significantly among grass species. Increasing EC significantly reduced plant biomass production of all species. All grass species experienced a 50% biomass reduction (GR_{50}) between 276 and 496 ECdays in 2008 and between 294 and 806 ECdays in 2009. Foxtail barley was the most salt tolerant (GR_{50} = 496 and 806 ECdays) requiring the highest salt exposure in 2008 and 2009 to experience a 50% biomass reduction. Grass mortality was greatly enhanced with increasing EC. Reed canarygrass and timothy were most susceptible to increasing salinity with 50% mortality (LD_{50}) of both grass species occurring between 983 and 1185 ECdays. Moderate salinity tolerance was exhibited by orchardgrass, which required 1977 and 1844 ECdays, creeping foxtail, which required 1998 and 2299

ECdays, and tall fescue, which required 2501 and >2840 ECdays to experience 50% mortality in 2008 and 2009, respectively. Foxtail barley, altai wildrye, and tall wheatgrass were most tolerant of salinity and persisted with little mortality occurring at 3033 and 2840 ECdays in 2008 and 2009, respectively. All grass species that had higher relative growth rates than foxtail barley and altai wildrye were more susceptible to salinity, with the exception of tall wheatgrass. Relative growth rates of foxtail barley and altai wildrye were significantly lower than the other grass species, which suggests that slower growth rates may aid in salinity tolerance.

Introduction

Foxtail barley (*Hordeum jubatum* L.) is a weedy, native, short-lived perennial bunchgrass that adversely alters the usefulness and productivity of many pastures throughout much of North America (Best et al. 1978; Cords 1960). Characteristic identification of foxtail barley is commonly due to its bluish to grayish-green leaf color and distinctive nodding seed heads (Whitson et al. 2000). Grazing livestock are adversely affected when seed heads of foxtail barley mature and produce stiff awns that can penetrate and become lodged in the mouth, eyes, ears, and skin; commonly leading to infection, irritation, weight loss, and other debilitating injuries (Best et al. 1978; Blouch 1953; Bowes 1984; Cords 1960). Forage quality and value of grasses grown for hay are also negatively affected by the presence of foxtail barley (White 1984). The adaptability and tolerance that foxtail barley exhibits in saline soils greatly exceeds that of many other pasture grasses and therefore explains its dominance in meadows, prairies, and pastures where salinity is a limiting factor (Badger and Ungar 1990; Dodd and Coupland 1966; Whitson et al. 2000).

Halophytes are plants that are tolerant and adapted to saline conditions. Halophytic plants are able to grow and complete their life cycles effectively in saline conditions (Badger and Unger 1990; Flowers and Colmer 2008), whereas glycophytes (salt sensitive plants) struggle to compete in similar environments (Flowers 1985). Tolerance mechanisms that enable high salinity tolerance in halophytic plants include 1) salt exclusion, 2) uptake and compartmentalization of salts, and 3) active extrusion of salts (Badger and Unger 1990; Cheeseman 1988; Gorham et al. 1985; Munns and Tester 2008; Parida and Das 2005; Rogers 2007). The utilization of these tolerance mechanisms give halophytes the advantage of performing more efficiently than glycophytes under saline conditions (Parida and Das 2005). Normally, halophytes utilize one or more of these mechanisms to achieve salinity tolerance. As a result of increased salinity tolerance, halophytes are generally the most dominant species in areas that experience high salinities (Dodd and Coupland 1966; Redmann 1972).

Foxtail barley is a halophyte which allows it to successfully establish in saline environments where other species are less competitive (Redmann 1972). Garthwaite et al. (2005) concluded that salt exclusion was the primary factor responsible for wild *Hordeum* species tolerance to salinity. Results from Badger and Ungar (1990) identify reduced uptake of Na^+ and a selective uptake of K^+ to be a significant mechanism of salt tolerance for *H. jubatum*, thus supporting the conclusions of Garthwaite et al. (2005). *H. jubatum* shows tolerance to multiple soil salinity levels (Best et al. 1978; Dodd and Coupland 1966), permitting it to established in areas where competition from other vegetation is limited (Cords 1960). Environmental changes such as salinity and flooding often influence *H. jubatum* dominance (Badger and Ungar 1990, 1994; Ungar and Riehl

1980). Observations from Dodd and Coupland (1966) showed *H. jubatum* establishment was most abundant on the drier edges of a depressed saline area gradient, often resulting in almost pure monotypic stands that occurred in large flat depressions or as a ring around deeper depressions.

Badger and Ungar (1990) established a soil salinity gradient and determined that *H. jubatum* is restricted to moderate zones of salinity where soils contain 0.3 to 0.9 percent total salts. However, results showed *H. jubatum* could survive salinities exceeding its physiological limits for growth and reproduction by surviving a number of weeks at 1.5 percent NaCl. Fluctuating soil moisture generates variable salt concentrations which create severe interference to the growth cycles of more desirable vegetation. This results in diminished competition from other vegetation, thus creating an environment more favorable to the establishment of *H. jubatum* (Badger and Ungar 1990; Cords 1960; Dodd and Coupland 1966). Cords (1960) determined that emergence of *H. jubatum* was suppressed at a three inch water table and fewer seedlings emerged from saline soils compared to non-saline soils. Results have shown that higher soil salinity concentrations caused an increase in *H. jubatum* mortality (Badger and Ungar 1994; Ungar 2001). Cords (1960) implied that poor emergence of *H. jubatum* in saline soils is compensated by higher seed production which results in higher establishment. In addition, Cords (1960) claims that *H. jubatum* is sensitive to salinity during the early growth period, but found that higher yields were produced in saline soils during the second year of the study. A study carried out by Wilson (1967) also showed higher yields of *H. jubatum* when grown under saline conditions.

Osmotic and ionic stresses created by salinity severely influence plant growth and productivity. As salinity increases plant growth decreases (Badger and Ungar 1990; Flowers 1985; Gorham et al. 1985; Munns and Tester 2008; Parida and Das 2005; Rogers 2007). Reduced growth in response to salinity allows plants to better conserve and utilize available resources. Species allocation in regard to leaf, stem, and root biomass changes the balance of photosynthesis, respiration (Flowers and Colmer 2008) and water uptake (Yang et al. 2009). Injury and death are amplified when plants expend excessive energy to achieve unnecessary growth in stressful environments. The ability to adapt and cope with unfavorable growing conditions largely determines a species tolerance to salinity. Soil and water containing excessive amounts of salt cause a reduction in water potential, which results in reduced and limited plant growth (Parida and Das 2005). Three requirements Zhu (2001) suggests plants must achieve in order to tolerate salinity are 1) damage must be prevented or alleviated, 2) homeostatic conditions must be re-established in the new stressful environment, and 3) growth must resume, albeit at a reduced rate.

An adaptive feature that permits greater plant survival in response to higher salinities is a more consistent growth rate. Growth rates have been found to play an important factor in salinity tolerance (Flowers 1985). Slower growth rates allow plants to utilize resources more efficiently. In comparison with *Hordeum vulgare,* Garthwaite et al. (2005) observed that wild *Hordeum* species had lower reductions in growth when exposed to saline conditions. Zhu (2001) emphasizes that salinity tolerance is inversely related to growth rate. Although halophytic plants such as *H. jubatum* may not generate as much biomass as other species, their competitive advantage comes from their ability to persist in saline conditions when other species succumb to salinity stress.

Salinity tolerance has often been assessed by exposing plants to sudden increases in external salinity stress. This sudden increase can result in enhanced mortality of many plant species due to the fact that many susceptible species are unable to adjust and adapt rapidly enough to debilitating saline conditions. Clipson and Flowers (1987) reported that halophytic plants are able to adjust to sudden increases of external salinity within 24 to 48 hours. Noaman et al. (2002) observed that the salt tolerance of wheat was enhanced when plants were gradually acclimated to salinity stress, whereas wheat was more susceptible to salinity when plants were suddenly shocked by high salt concentrations. In addition, they found that pretreating plants with abscisic acid (ABA) acts as a substitute for the acclimation period which allows plants to better tolerate salinity shock. Additionally, Umezawa et al. (2000) demonstrated improved survival and salt tolerance in soybean plants that received NaCl pretreatments prior to salt treatments; suggesting that plants can be acclimated to salinity and thereby be more tolerant of and better adapted to saline environments.

Growth stage is an aspect of salinity tolerance that Gorham et al. (1985) consider significant. In their study, Gorham et al. (1985) found that bread wheat that had flowered and less mature wild wheat exhibited significant tolerance differences when salt stress was applied. They concluded that the results may have been different had both plants been exposed to salt stress at the same growth stage. It is generally understood that young seedlings are more susceptible to environmental stresses, such as salinity, than more established and mature plants (Yang et al. 2009). Ungar (2001) proposes that a plant must be tolerant of salinity at both the germination and mature stages in order to become established in saline conditions. As a result of salinity tolerance, plants found in saline environments will produce salt tolerant seeds able to germinate and produce tolerant seedlings and eventual mature plants which can survive increased salinity levels (Arzani 2008; Baskin and Baskin 1998; Yang et al. 2009).

Hordeum jubatum has expressed high tolerance to salinity (Badger and Ungar 1990; Banting 1979; Cords 1960; Dodd and Coupland 1966; Garthwaite et al. 2005; Wilson 1967). As a result, desirable vegetation struggles to compete with *H. jubatum* because of the adverse growing conditions it inhabits. Salinity tolerance of desirable grass species has been determined in previous studies (Currie et al. 1986; Ludwig and McGinnies 1978; Miller and Chapman 1978; Roundy 1985; Venables and Wilkins 1978). Tall wheatgrass (Ludwig and McGinnies 1978; Miller and Chapman 1978; Roundy 1985) and altai wildrye (Currie et al. 1986) are two grass species that have been found to exhibit high salt tolerance. Other grass species have been found to be less tolerant of salinity.

Foxtail barley readily infests pastures in areas with elevated or high salinities. Due to unfavorable and adverse growing conditions found in these areas, many pasture grasses are unable to successfully establish and compete. The dominance exhibited by foxtail barley is largely the result of its high salt tolerance and a lack of competition from more desirable species. The objective of this study was to determine the relative tolerance of foxtail barley (*Hordeum jubatum*) and seven desirable pasture grasses to increasing salinity levels.

Methods and Materials

Salinity tolerance of foxtail barley and seven desirable pasture grasses was studied at the USDA-ARS Forage and Range research greenhouse in Logan, Utah. Grass seed of ‘Garrison’ creeping foxtail (*Alopecurus arundinaceus*), ‘Potomac’ orchardgrass

(*Dactylis glomerata*), 'Palaton' reed canarygrass (*Phalaris arundinacea*), 'Fawn' tall fescue (*Festuca arundinaceae*), 'Alkar' tall wheatgrass (*Thinopyrum ponticum*), and 'Climax' timothy (*Phleum pratense*) was obtained from Wheatland Seed Inc. in Brigham City, Utah. Seed of 'Mustang' altai wildrye (*Leymus angustus*) was acquired from the USDA-ARS Forage and Range Research Laboratory in Logan, Utah. Foxtail barley (*Hordeum jubatum*) seed was collected from an established infestation located in Cache Junction, Utah. The study was conducted twice (2008 and 2009) incorporating the same protocol established by Peel et al. (2004). This study was somewhat similar to the plastic cone-tainer method used by Lee et al. (2008); however, differences in plant submergence, salt concentrations, duration, and data collection occurred. The study was completed using a randomized complete block design with four replications. Each grass species consisted of 12 (2008) and 15 (2009) individual plants per replication. Grasses were planted individually in cone-tainers[1] with 70-grit silica sand. Capillary matting (10-by-10 cm square) was used to plug the bottom of the cone-tainers to prevent sand from washing out. Plants were hand watered daily with tap water until seedlings emerged. One week prior to salt treatments, all grasses were submerged twice in 20 percent nutrient (3 dS m^{-1}) solution for two minutes. After salt treatments were initiated, untreated grasses continued to be submerged in the nutrient solution while salt treated grasses were submerged in the salt solution. Grasses were cut to a uniform height (6 cm) before salt treatments were initiated. A NaCl and $CaCl_2$ salt solution was mixed in a tank covered with dark fabric to prevent algae growth from occurring. Grasses were immersed in the salt solution twice each week, for two minutes, for the duration of the study. Salt treatments began two months after grasses were planted, beginning with an electrical conductivity (EC) of 6 dS

m^{-1} and continued until an EC near 45 dS m^{-1} was reached. Electrical conductivity was increased by 3 dS m^{-1} increments every two weeks for the first six EC treatments (6, 9, 12, 15, 18, and 21 dS m^{-1}). Beginning at 24 dS m^{-1}, electrical conductivity was increased by 3 dS m^{-1} increments every week for the duration of the study. Sand remained moist between salt applications and grasses did not experience water stress.

Plant biomass was collected after each two week exposure to salinity of 6, 9, 12, 15, 18, and 21 dS m^{-1} EC (Table 3-1). Biomass samples were oven dried and weighed and GR_{50} values were determined when biomass was reduced by 50%. For each grass species at the lowest EC levels (6, 9, 12, 15, 18, and 21 dS m^{-1}), relative growth rates were determined by dividing the total biomass harvested from each grass species by the number of days plants were exposed to each EC. The relative growth rates show how many g day^{-1} each grass species produced in response to increasing EC (Figure 3-3). Beginning at the EC of 18 dS m^{-1}, plant death was determined visually and recorded each time grasses were immersed in the salt solution. LD_{50} values were determined when plant mortality reached 50%.

By using the same equation developed by Peel et al. (2004), a cumulative linear value was calculated to account for the number of days a plant was grown at each level of conductivity. This value is expressed as *ECdays* (Equation 1) and was calculated by multiplying the EC by the number of days at that level of conductivity and summed cumulatively over time, as shown:

$$\mathrm{ECdays}_i = \sum \left(\mathrm{EC}_1 \times \mathrm{D}_{\mathrm{EC}_1} + \mathrm{EC}_2 \times \mathrm{D}_{\mathrm{EC}_2} + \ldots\ \mathrm{EC}_i \times \mathrm{D}_{\mathrm{EC}_i}\right) \qquad [1]$$

where EC_i equals the ith electrical conductivity concentration, and D_{EC_i} indicates the number of days at the ith electrical conductivity concentration. ECdays were used to obtain linear values useful in comparing differences between grass species.

Data was analyzed as a repeated measures design due to the fact that data was collected from the same grasses over time during the duration of the study. Significant variety-by-treatment-by-run interactions prevented data from 2008 and 2009 from being combined. Data was fit to a 4-parameter logistic model (Equation 2) as shown:

$$Y = C + (D - C)/[1 + (x/GR_{50}\ or\ LD_{50})^{-b}] \qquad [2]$$

where C represents the lower limit, D indicates the upper limit, GR_{50} represents the number of ECdays required to cause a 50% reduction in biomass production, LD_{50} indicates the number of ECdays required to cause 50% plant mortality, and b is the slope of the line around the GR_{50} or LD_{50} values. The resulting GR_{50} and LD_{50} values provide an objective comparison of salinity tolerance between grass species.

Results and Discussion

Increasing EC noticeably reduced biomass production of all species (Figure 3-1). Foxtail barley required more ECdays than all other species to experience a 50% biomass reduction with GR_{50} values of 496 (2008) and 806 (2009) ECdays. In 2008 and 2009, altai wildrye followed foxtail barley with GR_{50} values occurring at 449 and 566 ECdays, respectively (Table 3-2). All other species experienced GR_{50} values by 335 (2008) and 456 (2009) ECdays. In 2008, foxtail barley and altai wildrye required 496 and 449

ECdays, respectively, to reduce biomass by 50% and were significantly different from all other species. However, in 2009 foxtail barley (GR_{50} = 806 ECdays) was significantly different from altai wildrye (GR_{50} = 566 ECdays). In 2008 and 2009 tall fescue (GR_{50} = 276 and 357 ECdays, respectively) and creeping foxtail (GR_{50} = 287 and 334 ECdays, respectively) were the first grasses to experience 50% biomass reduction (Table 3-2). These results agree with prior studies which have also found that increasing salinity significantly reduces and suppresses biomass production (Badger and Ungar 1990; Moxley et al. 1978; Parida and Das 2005; Parrondo et al. 1978; Rogers 2007). A recent salinity study of *Bromus inermis* seedlings executed by Yang et al. (2009) produced similar results. In their study they found that increasing salinity levels significantly reduced biomass and height of seedlings while increasing the root/shoot ratio. Yang et al. (2009) suggest that salinity stress causes plants to reallocate aboveground biomass to increase root biomass production which enables plants to increase water uptake and thereby alter salt concentrations.

Grass mortality differed significantly among grass species as salinity increased (Figure 3-2). In 2008 and 2009, Reed canarygrass (LD_{50} = 983 and 1066 ECdays, respectively) and timothy (LD_{50} = 1079 and 1185 ECdays, respectively) were most susceptible to increasing salinity, requiring fewer ECdays to experience 50% mortality (Table 3-3). These results are similar to recent results of Yang et al. (2009), which observed that survival percentages of *Bromus inermis* seedlings decreased significantly as salinity levels increased. Although seedlings were capable of surviving at lower salinities tested by Yang et al. (2009), seedlings eventually experienced 100% mortality at the highest salinities tested. In 2008 and 2009, Orchardgrass (LD_{50} = 1977 and 1844

ECdays, respectively), creeping foxtail (LD_{50} = 1998 and 2299 ECdays, respectively), and tall fescue (LD_{50} = 2501 and >2840 ECdays, respectively) showed moderate salt tolerance with 50% mortality occurring at higher EC levels and therefore tolerating more ECdays (Table 3-3). Tall wheatgrass, altai wildrye, and foxtail barley exhibited the highest salinity tolerances and did not experience significant mortality even at the highest EC tested (Table 3-3 and Figure 3-2).

Gorham et al. (1985) note that the growth stage of a plant significantly influences whether a plant is tolerant or sensitive to salinity. In this study grass species were not exposed to salinity stress until after germination and seedling establishment had occurred. However, Ungar (2001) proposes that a plant must be tolerant of salinity at both germination and maturity in order to become established in saline conditions. As a result of salinity tolerance, plants found in saline conditions will produce salt tolerant seeds able to germinate and produce tolerant seedlings which can survive increased salinity levels (Baskin and Baskin 1998; Yang et al. 2009). Although germination and seedling tolerance were not specifically evaluated in this study we assume that the grass species which were found to be most tolerant at more mature growth stages may also exhibit tolerance to salinity during germination and seedling establishment (Miller and Chapman 1978; Moxley et al. 1978; Roundy 1985). Additionally, Gorham et al. (1985) state that salinity tolerance should not be based on plant survival alone, but on additional factors such as biomass production and economic viability.

As mentioned, decreased biomass productivity and amplified plant death are detrimental effects imposed on plants exposed to saline conditions. Salinity tolerance exhibited by species is often influenced as a result of altered growth rates in adverse growing conditions. Tolerant species are able to more efficiently maintain important and critical growth functions in saline conditions. Parida and Das (2005) state that species differ significantly in tolerance and growth rate when exposed to lethal concentrations of salt. Data collected from this study shows that foxtail barley and altai wildrye have relative growth rates significantly different from the other grass species tested (Figure 3-3). Foxtail barley and altai wildrye did not produce as much biomass as the other grass species in both the salt treated and untreated experiments, but they persisted at the highest EC tested (Table 3-4). With the exception of tall wheatgrass, the remaining grass species which initially exhibited higher biomass production failed to persist at the highest EC tested. Tall wheatgrass, in addition to foxtail barley and altai wildrye, persisted at the highest EC tested and appears to be one of the most salt tolerant grasses in this study (Table 3-4). Tall wheatgrass has been found to be tolerant of salinity in previous studies and the results obtained from this study support those findings (Henry et al. 1987; Ludwig and McGinnies 1978; Miller and Chapman 1978; Moxley et al. 1978; Rogers 2007; Roundy 1985). In contrast to foxtail barley and altai wildrye, the relative growth rate of tall wheatgrass was much higher at lower EC (Figure 3-3). The ability to produce more biomass at lower EC could provide tall wheatgrass with a competitive advantage over foxtail barley and altai wildrye by occupying and thereby reducing space availability for other species.

Sources of Materials

[1]Cone-tainers, Stuewe and Sons Inc., 2290 SE Kiger Island Drive Corvallis, Oregon 97333-9425.

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Table 3-1. Targeted and measured electrical conductivity (EC) values of salt nutrient solution and biomass harvest schedule used to screen grasses for salinity tolerance in 2008 and 2009.

Time in solution	Electrical conductivity (EC)[a]				Biomass harvest schedule
	2008	2009	2008	2009	
	Targeted	Measured	Targeted	Measured	
wk	——— dS m^{-1} ———				
1	6	6.10	6	6.10	—
2	6	6.14	6	6.10	Biomass harvested
3	9	8.92	9	9.15	—
4	9	9.14	9	9.15	Biomass harvested
5	12	12.01	12	12.02	—
6	12	12.36	12	12.02	Biomass harvested
7	15	14.59	15	14.68	—
8	15	14.86	15	14.68	Biomass harvested
9	18	17.85	18	17.57	—
10	18	18.34	18	17.57	Biomass harvested
11	21	20.68	21	20.00	—
12	21	20.70	21	20.00	Biomass harvested
13	24	23.02	24	22.82	—
14	27	26.97	27	25.12	—
15	30	29.50	30	27.29	—
16	33	31.18	33	29.22	—
17	36	34.49	36	30.41	—
18	39	37.25	39	34.57	—
19	42	41.02	42	37.30	—
20	45	42.16	45	40.02	Biomass harvested

[a]Electrical conductivity at 25°C.

Table 3-2. Parameter estimates for non-linear regression of plant biomass in response to increasing ECdays (salinity x exposure).[a]

Variety	Year	C	D	GR_{50}	b	R^2
			ECdays[b]			
Foxtail barley	2008	5.47 (4.80)	97.60 (4.78)	495.55 (42.11)	2.53	0.99
	2009	3.95 (15.05)	82.67 (8.72)	805.51	2.22	0.95
Orchardgrass	2008	0.00 (3.57)	88.28 (6.51)	305.41 (32.49)	2.04	0.99
	2009	0.61 (6.02)	100.00	294.01 (48.54)	1.97	0.99
Creeping foxtail	2008	0.33 (5.23)	100.00 (9.47)	286.68 (36.18)	2.74	0.99
	2009	0.00 (2.03)	100.00 (3.07)	334.00 (14.06)	2.90	1.00
Timothy	2008	0.00 (2.06)	91.61 (3.15)	335.21 (15.99)	2.83	1.00
	2009	0.00 (1.52)	98.94 (1.72)	431.17 (10.55)	3.27	1.00
Tall fescue	2008	5.83 (3.01)	94.02 (5.93)	275.67 (24.83)	2.43	0.99
	2009	4.77 (2.76)	100.00 (3.85)	357.13 (20.80)	2.63	1.00
Reed canarygrass	2008	0.00 (1.80)	91.13 (3.35)	296.35 (15.38)	2.17	1.00
	2009	0.00 (2.81)	77.43 (3.21)	427.93 (24.85)	3.25	0.99
Altai wildrye	2008	0.00 (4.60)	100.00 (5.45)	448.65 (40.99)	1.66	1.00
	2009	1.69 (3.81)	100.00 (3.26)	565.96 (31.00)	2.84	1.00
Tall wheatgrass	2008	1.44 (2.61)	95.73 (4.49)	321.65 (22.65)	1.98	1.00
	2009	1.77 (1.04)	94.38 (1.13)	455.54 (9.19)	2.17	1.00

[a]Abbreviations: C, lower limit; D, upper limit; b slope of the line.
[b]Number of ECdays required to reduce plant biomass by 50%.

Table 3-3. Parameter estimates for non-linear regression of plant death in response to increasing ECdays (salinity x exposure).[a]

Variety	Year	C	D	LD_{50}	b	R^2
		ECdays[b]				
Foxtail barley	2008	–	–	>3033	–	–
	2009	–	–	>2840	–	–
Orchardgrass	2008	0.00 (3.47)	100.00	1977	8.89 (0.95)	0.99
	2009	0.00 (1.05)	100.00	1844 (7.85)	10.90	1.00
Creeping foxtail	2008	0.00 (3.76)	99.05 (0.92)	1998	7.06 (0.64)	0.99
	2009	16.38 (3.41)	100.00	2299	8.99 (0.59)	1.00
Timothy	2008	0.00 (0.73)	100.00	1079 (7.14)	7.78 (0.35)	1.00
	2009	0.12 (0.91)	100.00	1185 (8.92)	6.59 (0.29)	1.00
Tall fescue	2008	0.00 (10.57)	99.95 (0.86)	2501	8.55 (1.20)	0.98
	2009	0.00 (1.06)	100.00	>2840	6.35 (0.77)	0.99
Reed canarygrass	2008	0.00 (0.68)	99.46 (0.80)	983 (6.76)	7.32 (0.32)	1.00
	2009	0.00 (0.99)	100.00	1066	5.13 (0.23)	1.00
Altai wildrye	2008	–	–	>3033	–	–
	2009	–	–	>2840	–	–
Tall wheatgrass	2008	–	–	>3033	–	–
	2009	–	–	>2840	–	–

[a]Abbreviations: C, lower limit; D, upper limit; b slope of the line.
[b]Number of ECdays required to reduce plant survival by 50%.

Table 3-4. Ranking of grass species based on the number of ECdays[a] required to reach 50% mortality.

	LD_{50}		Rank	
Species[b]	2008	2009	2008	2009
	—— ECdays[c] ——			
Tall wheatgrass	>3033	>2840	1	1
Altai wildrye	>3033	>2840	2	2
Foxtail barley	>3033	>2840	3	3
Tall fescue	2501	>2840	4	4
Creeping foxtail	1998	2299	5	5
Orchardgrass	1977	1844	6	6
Timothy	1079	1185	7	7
Reed canarygrass	983	1066	8	8

[a]ECdays = electrical conductivity of salt solution multiplied by the number of days at a given electrical conductivity and summed across time.
[b]Species arranged by average rank.
[c]Number of ECdays required to reduce plant survival by 50%.

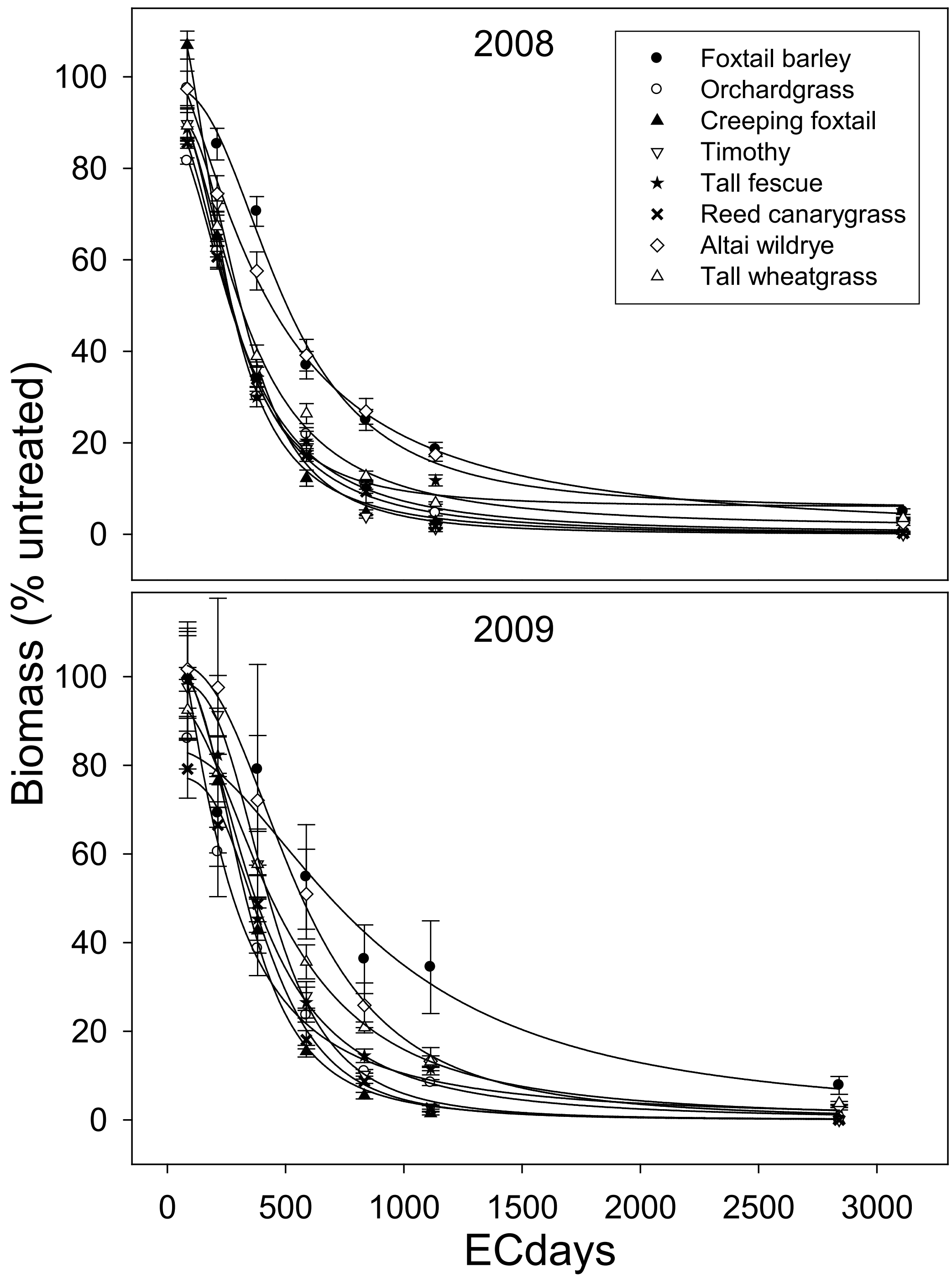

Figure 3-1. Grass species biomass response to increasing salinity exposure in 2008 and 2009 greenhouse experiments. Data was fit to a 4-parameter dose-response curve and parameter estimates for each curve are shown in Table 3-2.

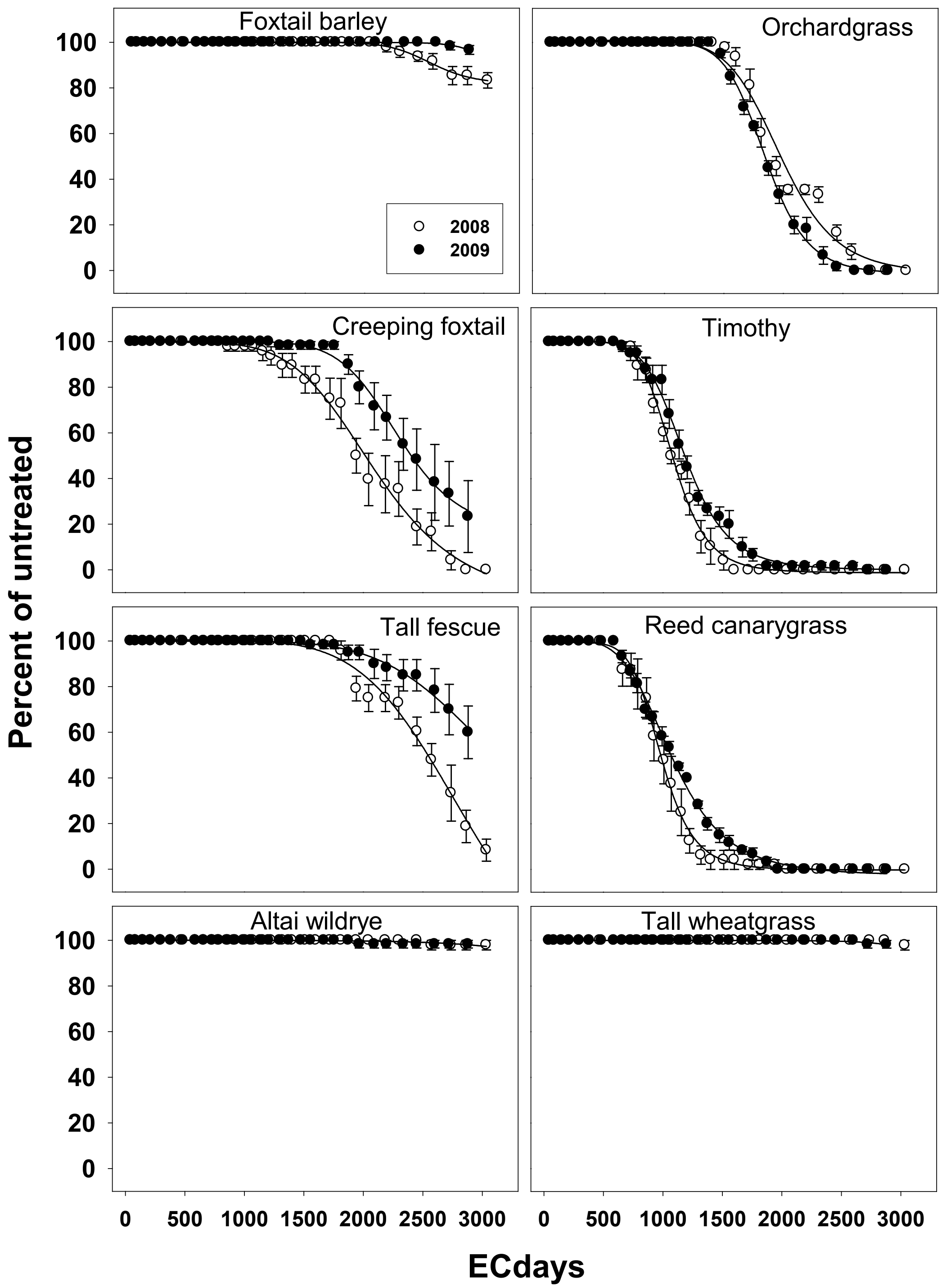

Figure 3-2. Grass species mortality in response to increasing ECdays in 2008 and 2009 greenhouse experiments. Data was fit to a 4-parameter dose-response curve and parameter estimates for each curve are shown in Table 3-3.

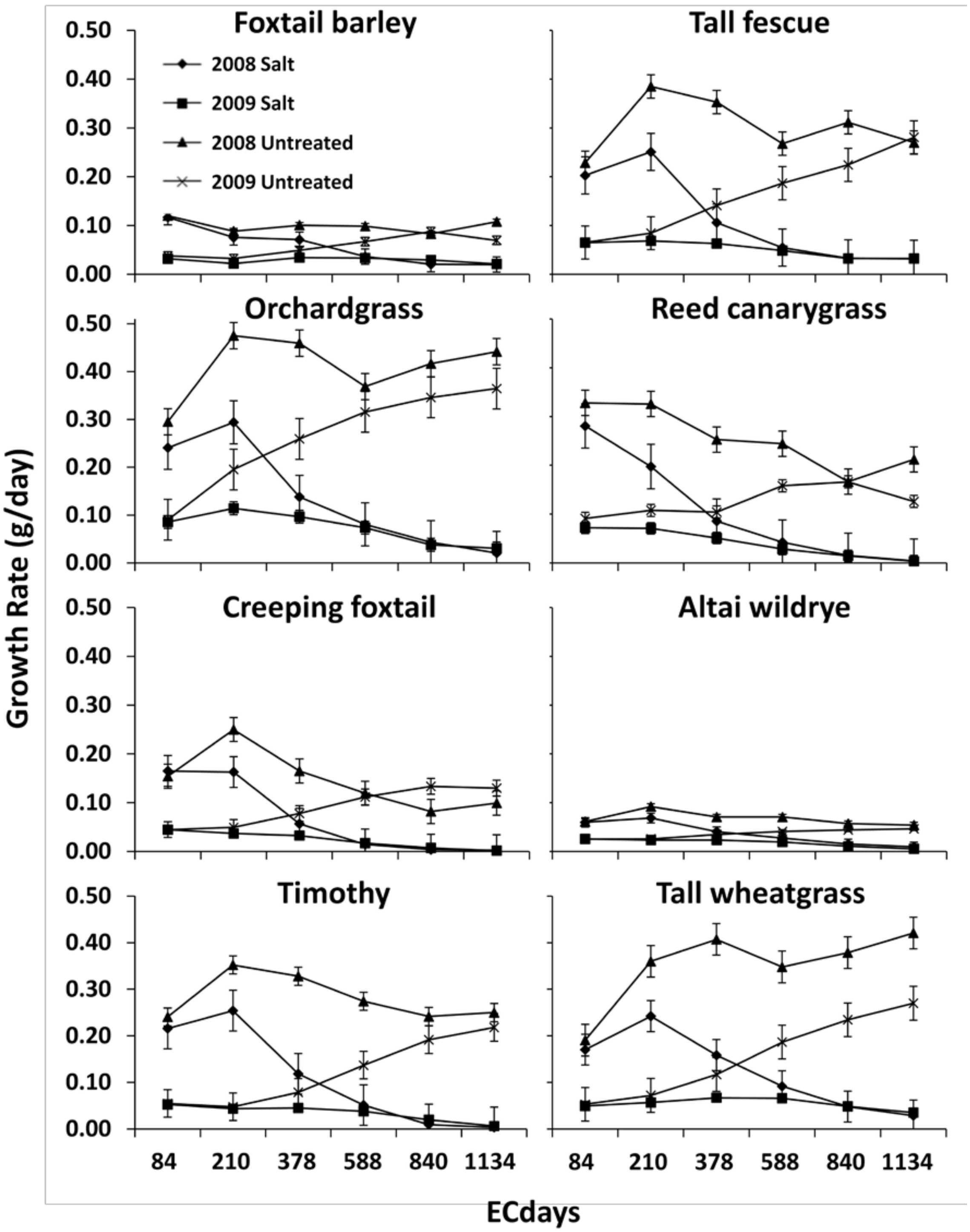

Figure 3-3. Relative growth rates of salt treated and untreated grass species at the six lowest EC levels tested in 2008 and 2009.

CHAPTER 4

FLOODING TOLERANCE OF FOXTAIL BARLEY (*Hordeum jubatum* L.) AND DESIRABLE PASTURE GRASSES

Abstract

A greenhouse study was conducted to determine the relative flooding tolerance of foxtail barley and six desirable pasture grasses. Grass species included in the study were 'Palaton' reed canarygrass (*Phalaris arundinacea*), 'Climax' timothy (*Phleum pratense*), 'Fawn' tall fescue (*Festuca arundinaceae*), 'Alkar' tall wheatgrass (*Thinopyrum ponticum*), 'Potomac' orchardgrass (*Dactylis glomerata*), 'Garrison' creeping foxtail (*Alopecurus arundinaceus*), and foxtail barley (*Hordeum jubatum*). Grasses were exposed to five flooding durations (0, 2, 4, 6, and 8 weeks). Flooding significantly influenced aboveground biomass, root biomass production, and height response of all the grass species tested. Flooded grasses yielded less aboveground biomass and root biomass compared to non-flooded treatments. With a few exceptions, flooding increased plant height when compared to non-flooded treatments. Overall, grasses which were able to extend above the water surface (18 cm) persisted at the longest duration tested

Introduction

The damaging effects inflicted by flooding impose detrimental stresses to plants in all locations. Plant responses to this limiting environmental stress largely determine species abundance and distribution in flood-prone ecosystems (Bailey-Serres and Voesenek 2008; McKenzie 1951). Flooding adversely affects essential growth functions in many plant species and is a major constraint to the productivity of crops and pasture species (Jackson and Colmer 2005). Susceptible plants which fail to maintain essential growth functions when exposed to flooding or waterlogged conditions experience accelerated injury and premature death (Blom 1999; Kozlowski 1984).

Oxygen deprivation is viewed as being the most debilitating factor upon flood stressed plants (Blom and Voesenek 1996; Kozlowski 1984; Sairam et al. 2008; Voesenek et al. 2006). According to Armstrong (1978), plants experience a reduced oxygen supply as a result of the slow diffusion rate of oxygen and its limited solubility when exposed to flood conditions. Sairam et al. (2008) state that photosynthesis and respiration are altered when flooding interferes with or blocks the transfer of oxygen and other gases between the atmosphere and soil and plants are negatively affected. Gas exchange between the soil and atmosphere is eliminated when soil pore space is completely water saturated (Drew 1983). In these oxygen deprived conditions, plants experience hypoxia (limited oxygen) or anoxia (complete absence) which greatly determines plant growth and survival (Drew 1997; Jackson and Colmer 2005; Voesenek et al. 2006). Sairam et al. (2008) indicate hypoxia most commonly occurs during short-term waterlogged conditions when only roots are submerged in water; while anoxia occurs in long-term flooding when plants are completely submerged in water.

Heavy rainfall, spring runoff, and soil drainage contribute greatly to flooding duration and intensity (Blom and Voesenek 1996). Waterlogged, submerged or inundated, and flooded, are terms used in reference to excessive water accumulation, however, these terms are viewed differently according to water levels. Jackson (2008) and Rubio et al. (1995) classify waterlogging as the submergence of the soil-based root system. Submersion or inundation occurs when all vegetation is completely encased with water (Blom and Voesenek 1996; Kirkman and Sharitz 1993; Lenssen et al. 2000). Although each term defines specific environmental conditions; all terms can be collectively referred to as flooding.

Specific factors that impact flooding tolerance consist of plant species, duration, timing/growth stage, water depth, water conditions, and temperature. Kozlowski (1984) suggests that angiosperms are typically more tolerant of flooding than gymnosperms but noted that flood tolerance varies widely depending on species (Rhoades 1964), cultivars, and ecotypes. McKenzie (1951) determined that grasses tolerated flooding better than legumes.

Flooding duration greatly affects a plants ability to survive and persist (Kirkman and Sharitz 1993). Bolton and McKenzie (1946) imply that in order for a plant to successfully survive and compete it must tolerate the longest period of flooding. Prolonged flooding increases plant stress, which depletes energy reserves. Plant mortality increases if energy reserves are depleted before flooding dissipates (Bailey-Serres and Voesenek 2008; Jackson 2008). Blom and Voesenek (1996) indicate that flooding duration is often unpredictable due to unforeseen weather patterns as well as other environmental and human disturbances.

Timing and growth stage are additional factors that significantly impact flood tolerance (Colmer and Flowers 2008; Kirkman and Sharitz 1993). Germination and seedling establishment are viewed as perhaps the most vulnerable growth periods in a plants life cycle (Baskin and Baskin 1998; Blom 1999; Cavers and Harper 1967; Fenner 1987). Species studied by McKenzie (1951) showed comparable tolerance between seedling and mature growth stages. However, some species were less tolerant at the seedling stage which supports conclusions made by Blom (1999) that flooding tolerance generally increases with age. Previous studies have found that flooding during the growing season is often more detrimental than flooding that occurs when plants are dormant (Blom 1999; Gill 1970; Kozlowski 1984; Mittra and Stickler 1961; Rhoades 1967; Siebel and Blom 1998).

Flood waters do not need to completely inundate or submerge plants in order to be fatal (Armstrong et al. 1994). Intolerant species frequently experience fatal damage when only soil is saturated (Jackson 2008) and plant community dominance changes according to water depth (Kirkman and Sharitz 1993). Light transmission and photosynthesis are directly influenced by water depth (Blom and Voesenek 1996; Voesenek et al. 2006). Vervuren et al. (2003) observed that light transmission was reduced significantly as depth increased. Due to the shading effect and decreased light transmission caused by suspended particles in flood water, photosynthesis is severely limited (Bailey-Serres and Voesenek 2008; Vervuren et al. 2003). Under submerged conditions plants are unable to access atmospheric oxygen and carbon dioxide (Colmer and Flowers 2008) which are critical for photosynthesis to occur; and in most cases unless plants are able to extend above the water surface photosynthesis ceases and death results (Jackson and Colmer 2005). Results obtained by Davis and Martin (1949) along with Beard and Martin (1970) showed that grasses with leaves extending above the water surface survived much longer than submerged grasses. In a study carried out by Rhoades (1967) grasses were exposed to flooding depths up to 6 feet. Results from this study showed that grass injury was greatly enhanced as depth increased.

Outcomes from previous studies have found that flooding tolerance decreases in stagnant water when compared with moving water (Armstrong et al. 1994; Davis and Martin 1949). Beard and Martin (1970) acquired similar results and determined that higher temperatures occurring in shallow standing water enhanced injury compared to lower temperatures in continuously flowing water. In addition to lower temperatures, Davis and Martin (1949) suggest a greater amount of available oxygen in moving water as a possible explanation for improved flood tolerance. Jackson (2008) states that submergence in stagnant or slow-moving water threatens all but the very simplest forms of plant life. In agreement with the above mentioned conclusions, Kozlowski (1984) implies that even flood tolerant plants are more susceptible to injury in standing water.

As mentioned previously, temperature functions as an important factor of flood tolerance. Colmer and Flowers (2008) and Drew (1983) cite warmer temperatures as the enhancer of oxygen depletion. Soil respiration is slowed when temperatures are low, thus conserving oxygen reserves (Drew 1983). Trought and Drew (1982) found that warm temperatures can deplete oxygen from the soil within hours. Winter temperatures required 13 days to deplete soil oxygen concentrations, whereas only 3.5 days were needed with spring temperatures (Drew 1983).

Tolerant species frequently employ tolerance mechanisms for added resilience and escape from flooding conditions (Jackson 2008). In many cases adaptive traits allow flood tolerant species to be highly successful and productive in adverse growing conditions (Blom 1999; Jackson and Colmer 2005). Adaptive characteristics which have proven crucial for survival in hypoxic and anoxic growth environments consist of morphological (Bailey-Serres and Voesenek 2008; Blom 1999; Drew 1983; Mahelka

2006), physiological (Blom 1999; Drew 1983; Jackson and Colmer 2005; Mahelka 2006), anatomical (Bailey-Serres and Voesenek 2008; Blom 1999; Drew 1983; Mahelka 2006; Perata and Alpi 1993), structural (Armstrong et al. 1991; Drew 1983), and metabolic (Blom 1999; Drew 1983; Perata and Alpi 1993) features. Each adaptive characteristic permits plants to perform critical growth functions while exposed to flooding stresses. Plant species do not need to exhibit all the above mentioned tolerance mechanisms to be flood tolerant. However, flood tolerance should not be associated exclusively to a single characteristic, but a combination of interacting adaptive characteristics (Drew 1983; Perata and Alpi 1993).

Some of the most commonly recognized adaptive characteristics utilized by tolerant species include aerenchyma formation (Bailey-Serres and Voesenek 2008; Blom 1999; Blom and Voesenek 1996; Colmer and Flowers 2008; Drew 1983; Jackson and Colmer 2005; Kozlowski 1984; Sairam et al. 2008; Voesenek et al. 2006), elongation (Bailey-Serres and Voesenek 2008; Blom 1999; Blom and Voesenek 1996; Colmer and Flowers 2008; Jackson 2008; Jackson and Colmer 2005; Lenssen et al. 2000; Mahelka 2006; Voesenek et al. 2006), adventitious root development (Blom 1999; Blom and Voesenek 1996; Colmer and Flowers 2008; Drew 1983; Kozlowski 1984; Rubio et al. 1995; Sairam et al. 2008), and stomatal closure (Drew 1983; Kozlowski 1984; Sojka and Stolzy 1980). Each adaptation provides beneficial and supportive escape and avoidance capabilities; specifically when access to oxygen supply sources is impeded or eliminated (Bailey-Serres and Voesenek 2008; Jackson and Colmer 2005).

Jackson and Colmer (2005) classify aerenchyma as the most characteristic adaptive feature of flood tolerance. Aerenchyma formation allows plants to tolerate extended periods of flooding by enabling the diffusion of oxygen from the air to plant roots (Blom and Voesenek 1996; Colmer and Flowers 2008; Sairam et al. 2008; Voesenek et al. 2006). Blom (1999) as well as Jackson and Armstrong (1999) consider aerenchyma formation as the most common and important adaptation of many flood tolerant species. In most species aerenchyma is absent until it is induced by the occurrence of flooding (Armstrong 1979; Bailey-Serres and Voesenek 2008; Colmer 2003; Voesenek et al. 2006). Drew et al. (2000) concluded that aerenchyma can form in new and existing plant tissues. Aerenchyma consists of soft tissues with large intercellular spaces which allow gas exchange to occur between aerobic shoots and anaerobic roots (Sairam et al. 2008). The formation of aerenchyma is important for survival in both partial and complete submergence and has been found to develop primarily in roots, but also in shoot organs and stems of specific species (Bailey-Serres and Voesenek 2008; Kozlowski 1984). Drew (1983) noted that aerenchyma should not always be associated with flood survival. Although many species utilize aerenchyma for survival, some species can tolerate and survive flooding without aerenchyma.

Elongation is one of the most widespread escape mechanisms employed by flood stressed species (Jackson 2008). Regaining contact with the aerial environment (Bailey-Serres and Voesenek 2008; Blom and Voesenek 1996; Jackson and Colmer 2005; Voesenek et al. 2006) provides an accessible oxygen supply for plant roots, thus increasing the chance of survival for many species (Jackson 2008; Lenssen et al. 2000). Leaves that extend above the water surface act as snorkels which permits gas exchange to occur between the aerial environment and submerged roots (Bailey-Serres and Voesenek 2008; Colmer 2003; Visser et al. 1997). Colmer and Flowers (2008) note that in addition to gas exchange; elongation promotes the continuation of photosynthesis by reestablishing contact with light. Flowering and seed production can also be stimulated as a result of elongation (Blom and Voesenek 1996; Kirkman and Sharitz 1993). Jackson (2008) in agreement with Bailey-Serres and Voesenek (2008) emphasizes that elongation is signaled primarily by the gaseous hormone ethylene as well as abscisic acid (ABA) and gibberellin (GA). Elongation requires energy and carbohydrates for cell division and synthesis of new cell-wall material (Voesenek et al. 2006). If submerged plants are unable to extend beyond the water surface due to excessive water depths, energy reserves can be extinguished and mortality is amplified (Jackson and Colmer 2005; Voesenek et al. 2006). As a result of elongation, flooded plants often generate more biomass than non-flooded plants (Lenssen et al. 2000; Rubio et al. 1995). Kirkman and Sharitz (1993) observed that inundated plants grew twice as tall as plants in moist soil. Although biomass production can increase as a result of flooding and elongation, Lenssen et al. (2000) caution that biomass production does not always accurately assess flood tolerance.

The development of adventitious roots is another trait utilized by plants to increase waterlogging tolerance (Colmer and Flowers 2008). Adventitious roots grow close to the water surface enabling them to better access available oxygen in water and the upper soil layers (Blom and Voesenek 1996; Rubio et al. 1995; Sairam et al. 2008). Ethylene and auxins have been found to aide in the formation of adventitious roots (Blom 1999). Drew (1983) states that adventitious roots also develop aerenchyma; thereby improving plant fitness in flood conditions. Adventitious root development can be impacted when flood waters are saline (Colmer and Flowers 2008). A perennial grass studied by Naidoo and Mundree (1993) did not show a reduction in the development of adventitious roots. However, Salter et al. (2007) noticed that saline flood water reduced the adventitious root development of a salt-tolerant semi-xerophyte tree and a halophytic tree.

Kozlowski (1984) observed that stomatal closure occurred within a couple days after flooding occurred. In addition to this observation, Kozlowski (1984) noted that when stomata of intolerant species failed to reopen after a long period of time increased injury often resulted. However, tolerant species reopened stomata after about two weeks which correlated with the production of adventitious roots. Drew (1983) and Kozlowski (1984) both saw a reduction of transpiration and photosynthesis due to stomatal closure. Sojka and Stolzy (1980) along with Kozlowski (1984) observed that when stomata of flooded plants closed leaves did not become dehydrated or wilted.

Voesenek et al. (2006) suggest that for a plant to react appropriately to flooding it must be able to sense when environmental changes happen. Bailey-Serres and Voesenek (2008) say understanding is limited in regard to mechanisms used by plants to sense and initiate changes in response to oxygen deficiencies caused by flooding. They also suggest that a gradual transition period from desirable growing conditions to hypoxia or anoxia may provide a better opportunity for plants to adjust to stressful conditions, thereby improving flood tolerance. Drew (1997) found survival rates to be higher when plants were exposed to hypoxia for 2 to 4 hours to prior transitioning to anoxic conditions. In contrast, plants that were abruptly exposed to anoxic conditions without a transition period suffered higher mortality rates after experiencing flooding or anoxic shock.

Plant species that are capable of readily adapting to adverse flooding conditions exhibit greater dominance over less tolerant species. Foxtail barley is a short-lived perennial grass that has successfully adapted to flood-prone environments. Its ability to establish and reproduce in these adverse environments makes it difficult to displace with more desirable and often less tolerant species. The objective of this research was to determine the relative flood tolerance of foxtail barley and six desirable pasture grasses. Individual differences were observed by recording height, biomass, and death of all grasses grown in both flooded and non-flooded conditions in a greenhouse.

Methods and Materials

Flooding tolerance of foxtail barley and six desirable grasses was studied at the Utah State University Research Greenhouse in Logan, Utah. Grass seed of 'Garrison' creeping foxtail (*Alopecurus arundinaceus*), 'Potomac' orchardgrass (*Dactylis glomerata*), 'Palaton' reed canarygrass (*Phalaris arundinacea*), 'Fawn' tall fescue (*Festuca arundinaceae*), 'Alkar' tall wheatgrass (*Thinopyrum ponticum*), and 'Climax' timothy (*Phleum pratense*) was obtained from Wheatland Seed in Brigham City, Utah. Foxtail barley (*Hordeum jubatum*) seed was collected from an established patch located in Cache Junction, Utah. Six individual grass plants were planted in 10 by 10 cm square pots filled with sand. The study consisted of four replications of each grass species (1 pot/species/rep) and four flood intervals (2, 4, 6, and 8 weeks) with an unflooded check for each flood interval. The experiment was conducted twice. Each flood interval (4) consisted of eight pots (4 flooded 4 unflooded) per species (7) for a total of 224 pots. In addition to the 224 pots, four pots of each grass species were harvested prior to flooding treatments to determine initial height and biomass. Six weeks after planting, grasses were cut to a uniform height of 6 cm. Grasses were allowed to regrow for 2 weeks and flooding was initiated 8 weeks after grasses were planted. Flooded grasses were placed in water 18 cm above the soil surface. Water was cycled weekly with fresh water while maintaining a depth of 18 cm above the soil surface. Water temperature ranged from 15 to 20 (Avg. 18) degrees C. Air temperatures ranged from 25 to 30 (Avg. 27) degrees C. Relative air humidity ranged from 34 to 52 (Avg. 43) percent. Unflooded grasses were watered regularly. Specified grasses were removed at each flood interval at which time height was measured and biomass (6 cm aboveground) was collected. Grasses were then allowed to regrow for two additional weeks at which time height regrowth was measured and aboveground biomass regrowth (6 cm aboveground) and roots were harvested. Biomass samples were oven dried and weighed.

Data from run one and run two were not combined due to differences between species and treatment. However, initial growth and regrowth data of aboveground biomass and roots within respective runs were combined and compared between species and treatment (Figure 4-1). Comparisons were also determined between species in regard to plant height and treatment (Figure 4-2).

Results and Discussion

Flooding significantly influenced the growth of all grass species tested. The aboveground biomass and root biomass of all species was greatest in controlled treatments when compared to flooded treatments in both runs, with the exception of timothy and creeping foxtail which produced more aboveground biomass when flooded in run two (Table 4-1 and 4-2; Figure 4-1 and 4-2). Flooded foxtail barley appears to have a high flood tolerance although it did not yield as much aboveground biomass as timothy or creeping foxtail. Results reported by Rubio et al. (1995) stated that the aboveground biomass was greater and root biomass was less when species were flooded compared to non-flooded treatments. Results from this study agree with results obtained by Rubio et al. (1995) in regard to root biomass production (Table 4-2; Figure 4-2). However, aboveground biomass results from this study conflict with the reported results of Rubio et al. (1995). In addition to different species selection, another explanation for the aboveground biomass differences is that although control treatments generally did not grow as tall as flooded grasses, their growth was more dense or thick, resulting in higher biomass accumulation (Table 4-1; Figure 4-1). High biomass production in flood conditions does not necessarily equate to high flood tolerance, although it can be viewed as an indicator of flood tolerance.

Elongation appeared to be the mechanism utilized by the majority of grass species in this study to tolerate flooding, which agrees with the conclusions made by Jackson (2008). When flooded, timothy, creeping foxtail, and reed canarygrass had taller plants heights in both runs when compared to control treatments. This increased shoot elongation appears to have aided in their flooding tolerance (Table 4-3; Figure 4-3). Overall, foxtail barley height was equal to or greater than all other grass species in both runs, although control treatments exhibited slightly taller plants. Tall fescue, tall wheatgrass, and orchardgrass did not exhibit the same degree of flood tolerance as the other grass species which appears to be a result of shorter grass height (Table 4-3; Figure 4-3). In agreement with previous studies, it was observed that the grass species which were able to extend above the water surface tolerated the highest flooding durations, while grasses which failed to extend above the water surface were unable to persist when their limited growth resources were expended (Bailey-Serres and Voesenek 2008; Blom and Voesenek 1996; Jackson 2008; Jackson and Colmer 2005; Lenssen et al. 2000; Voesenek et al. 2006). Generally, flooded grass species in this study grew taller than non-flooded grasses (Table 4-3; Figure 4-3); however, they did not grow twice as tall as the controlled species that Kirkman and Sharitz (1993) observed from results in their study.

It is interesting to note that foxtail barley was the only species to produce seed during the course of the study (data not displayed). This observation can help explain why foxtail barley appears to be better adapted and more successful in establishing in areas that experience seasonal flooding. Although other species may have high flood tolerance, their ability to successfully establish in areas where seasonal flooding occurs can be influenced significantly by their failure to produce seed.

Results from this study failed to accurately clarify flooding tolerance of the tested grass species. However, general differences which were observed among the grass species can aid in the design of future flooding experiments and should be evaluated more extensively. Critical factors such as growth stage, water depth, germination, and duration should be considered or included in future experiments to better assess species response to flooding.

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Table 4-1. Aboveground biomass values of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

		Aboveground biomass			
		Flood		Control	
Species	Duration	Run 1	Run 2	Run 1	Run 2
	wks	g			
Timothy	0	1.19	1.40	1.19	1.40
	2	3.48	5.79	3.89	3.96
	4	5.64	7.77	5.89	6.16
	6	6.14	10.25	8.35	8.02
	8	8.61	12.32	9.44	9.51
Tall fescue	0	0.49	1.64	0.49	1.64
	2	1.38	3.73	3.35	4.32
	4	2.31	4.21	3.57	5.74
	6	2.78	4.85	4.23	8.36
	8	3.44	8.50	6.81	10.38
Tall wheatgrass	0	0.68	0.90	0.68	0.90
	2	1.30	2.48	3.18	2.91
	4	1.65	3.34	2.51	3.74
	6	1.94	4.19	4.32	4.34
	8	2.74	4.40	6.95	5.74
Foxtail barley	0	0.50	0.92	0.50	0.92
	2	2.06	2.42	2.94	2.23
	4	4.41	3.83	3.93	3.38
	6	4.53	5.37	4.17	5.22
	8	5.26	5.74	5.28	7.01
Creeping foxtail	0	1.05	0.80	1.05	0.80
	2	2.55	4.03	2.82	2.04
	4	4.22	5.92	3.82	3.23
	6	6.04	9.02	6.11	3.91
	8	8.14	11.20	8.53	4.09
Reed canarygrass	0	0.24	1.11	0.24	1.11
	2	0.79	1.62	3.17	2.62
	4	2.23	1.52	4.36	4.08
	6	2.25	2.45	7.21	4.43
	8	3.93	3.76	10.13	6.92
Orchardgrass	0	0.96	1.69	0.96	1.69
	2	2.09	3.47	3.24	4.02
	4	2.80	4.18	2.89	4.51
	6	2.66	4.71	4.40	6.26
	8	1.86	5.58	3.62	7.47

Table 4-2. Root biomass values of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

		Root biomass			
		Flood		Control	
Species	Duration	Run 1	Run 2	Run 1	Run 2
	wks	g			
Timothy	0	2.94	2.48	2.94	2.48
	2	4.77	4.16	6.18	4.17
	4	3.48	5.83	6.27	7.09
	6	4.22	6.28	10.05	12.67
	8	8.66	5.22	14.93	12.76
Tall fescue	0	0.49	2.58	0.49	2.58
	2	1.10	4.87	2.53	7.16
	4	0.25	3.39	3.75	8.78
	6	0.43	3.29	5.17	14.57
	8	0.80	3.10	8.70	16.16
Tall wheatgrass	0	0.46	1.77	0.46	1.77
	2	0.79	3.03	1.66	3.57
	4	0.44	2.24	2.16	4.64
	6	0.31	2.68	3.30	5.54
	8	0.29	2.65	3.97	7.79
Foxtail barley	0	0.32	1.05	0.32	1.05
	2	0.67	1.43	1.03	1.55
	4	0.78	1.58	1.52	2.31
	6	0.93	1.66	2.25	3.46
	8	1.07	1.86	2.85	4.14
Creeping foxtail	0	1.38	2.15	1.38	2.15
	2	2.28	3.49	4.19	5.40
	4	3.23	3.94	7.14	10.87
	6	6.81	5.96	12.80	12.09
	8	10.15	9.48	20.78	14.36
Reed canarygrass	0	0.17	1.18	0.17	1.18
	2	0.59	2.41	1.17	2.76
	4	0.65	2.46	1.10	4.74
	6	0.75	4.03	2.34	5.52
	8	1.28	5.52	4.27	9.73
Orchardgrass	0	1.03	2.03	1.03	2.03
	2	1.08	2.45	2.12	2.36
	4	0.59	2.00	1.97	3.31
	6	0.47	1.91	3.33	4.14
	8	0.47	1.24	4.20	5.51

Table 4-3. Height of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

		Height			
		Flood		Control	
Species	Duration	Run 1	Run 2	Run 1	Run 2
	wks	cm			
Timothy	0	32.75	15.25	32.75	15.25
	2	79.75	65.50	81.00	36.00
	4	80.25	73.25	73.00	40.00
	6	79.25	71.25	59.50	38.25
	8	75.25	70.50	62.00	36.25
Tall fescue	0	21.00	12.00	21.00	12.00
	2	46.75	37.25	55.50	22.50
	4	35.75	58.75	44.75	29.25
	6	42.00	60.25	41.00	28.75
	8	32.50	49.75	36.75	25.00
Tall wheatgrass	0	23.50	13.25	23.50	13.25
	2	58.25	51.75	58.75	34.75
	4	39.75	59.50	49.75	32.75
	6	29.75	60.50	43.50	29.00
	8	24.25	65.25	45.75	26.25
Foxtail barley	0	34.75	32.75	34.75	32.75
	2	73.50	78.25	79.00	76.25
	4	85.00	74.25	76.75	75.25
	6	83.25	80.50	84.50	74.50
	8	84.75	75.00	93.75	78.25
Creeping foxtail	0	29.25	8.00	29.25	8.00
	2	77.25	66.75	71.75	30.50
	4	93.75	74.50	66.50	36.75
	6	84.00	80.75	70.25	32.00
	8	88.00	82.25	66.50	28.00
Reed canarygrass	0	16.75	21.50	16.75	21.50
	2	55.00	62.75	55.25	43.25
	4	70.25	67.25	46.25	53.75
	6	68.50	74.00	57.25	51.50
	8	73.25	78.25	66.00	54.50
Orchardgrass	0	29.00	20.25	29.00	20.25
	2	72.75	70.50	68.25	46.50
	4	69.50	70.25	53.50	42.00
	6	37.00	51.50	49.50	38.25
	8	29.00	22.50	50.25	38.00

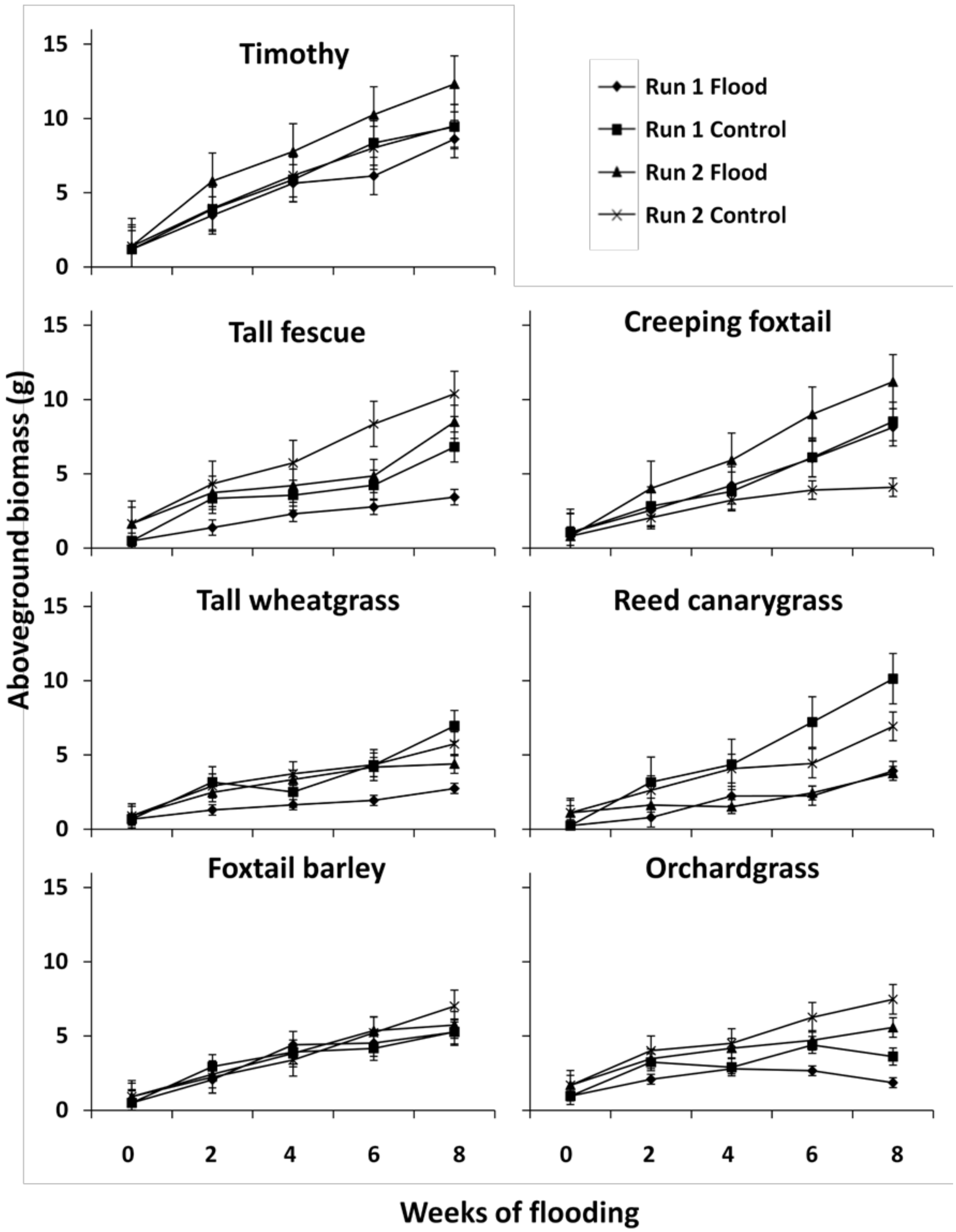

Figure 4-1. Aboveground biomass production of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

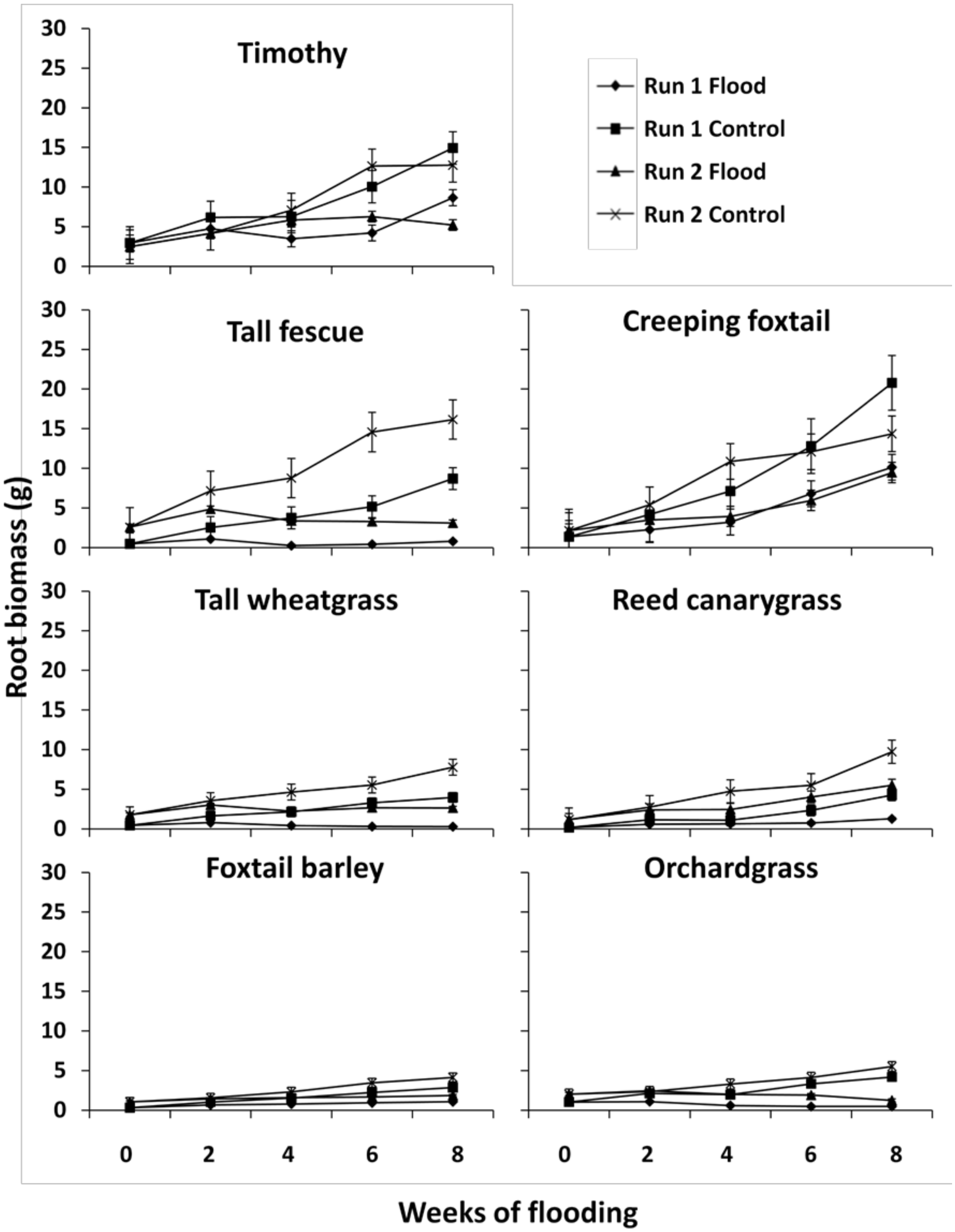

Figure 4-2. Root biomass production of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

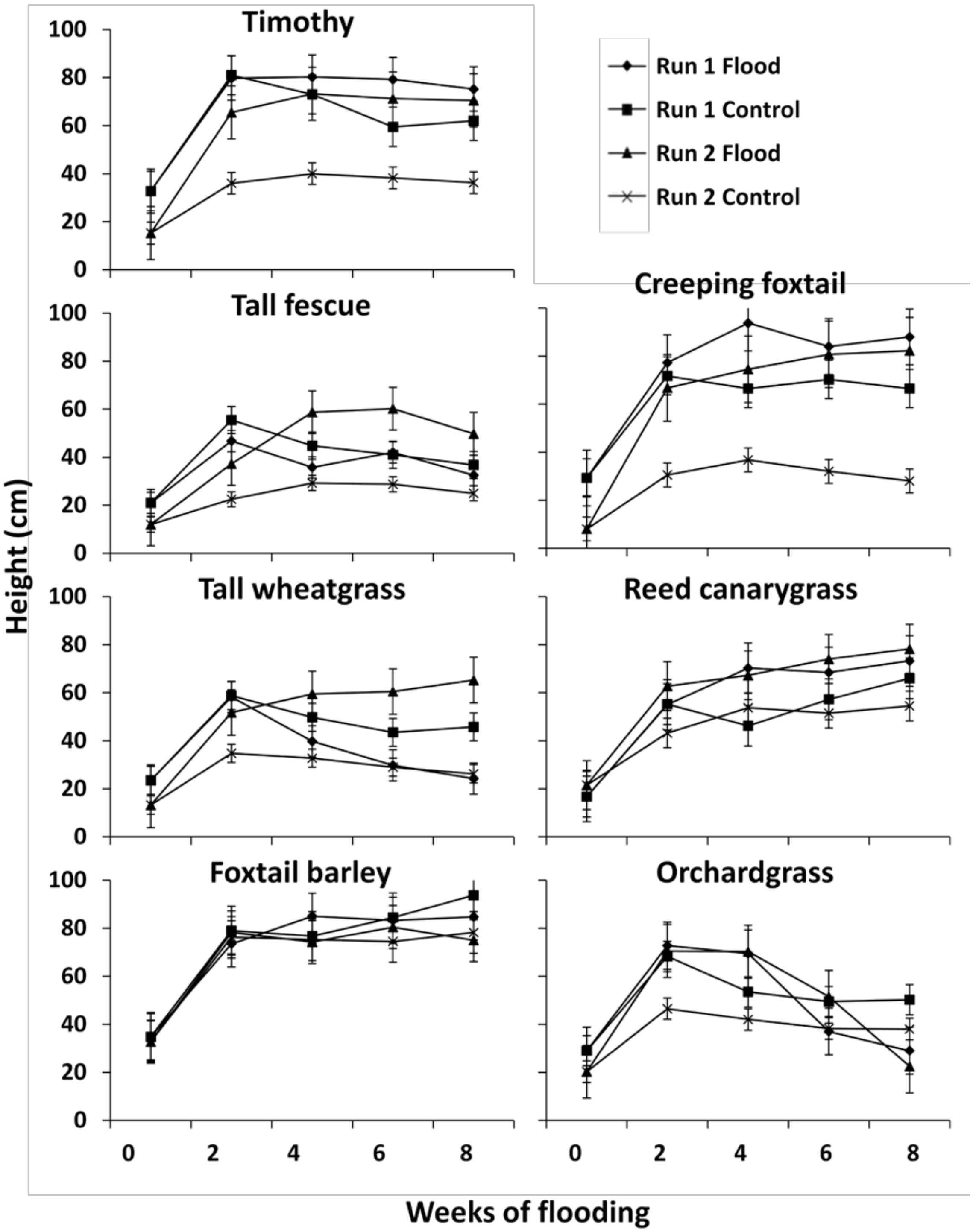

Figure 4-3. Height response of grass species exposed to 0, 2, 4, 6, and 8 weeks of flooding with paired control groups.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Selecting grass species that can tolerate the limiting environmental factors of salinity and flooding are crucial to the successful management and control of foxtail barley. In addition to grass species tolerance to salinity and flooding, herbicide tolerance can greatly enhance the competitive ability of desirable grass species over foxtail barley. Desirable grass species which are able to establish, persist, and compete in areas typically dominated by foxtail barley, significantly reduce the invasive ability of foxtail barley.

Results from this research can assist landowners in better determining the most appropriate grass species to establish for their respective situation. Salinity concentrations and flooding intensities can vary dramatically in different locations, thereby requiring the selection of the best suited grass species in each location to ensure establishment. A better understanding of the expected tolerance capabilities of desirable grass species to herbicides, salinity, and flooding can greatly improve the success of foxtail barley control.

Herbicide tolerance was variable between all the grass species and herbicides. With a few exceptions, grass species did not show high herbicide tolerance. Tall wheatgrass displayed a very high tolerance of flucarbazone and did not experience a 50% biomass reduction at the highest rate (200 g ha^{-1}) tested. Foxtail barley, however, also displayed a fairly high tolerance of flucarbazone and most likely would not be controlled satisfactorily at the recommended use rate of 29 g ha^{-1}. Orchardgrass exhibited high tolerance to propoxycarbazone at rates near the recommended use rate of 29-44 g ha^{-1}. Foxtail barley was not tolerant of propoxycarbazone and experienced significant biomass reduction at the lower rates tested. The tolerance of orchardgrass and susceptibility of foxtail barley to propoxycarbazone may allow propoxycarbazone to be used to selectively control foxtail barley in orchardgrass.

Tall wheatgrass and altai wildrye are grasses which exhibited a high tolerance to salinity, and persisted with foxtail barley at the highest EC tested. Both grasses appear to have the capability of competing with foxtail barley at very high salinities. However, due to higher biomass production at lower EC levels, tall wheatgrass may have a more competitive advantage by crowding out and limiting the space availability of foxtail barley. Additionally, it is important to note that although tall fescue, creeping foxtail, and orchardgrass did not persist at the highest EC tested; these grasses did exhibit tolerance to elevated EC levels and should also be considered as viable options in areas that experience higher salinities. Reed canarygrass and timothy did not exhibit high salinity tolerance and do not appear to be a practical option in areas with elevated salt concentrations.

Grass species responded to flooding by growing to extend above the water surface. Flooded grasses grew taller than non-flooded grasses. Plants that failed to extend and then maintain shoots above the water surface experienced higher rates of mortality. Foxtail barley exhibited flood tolerance while showing more consistent growth between flooded and non-flooded plants and was the only grass to produce seed within the duration of the study. This ability to produce seed may help explain why foxtail barley is successful in establishing and persisting in flooded areas. Flood tolerance was also observed in timothy, creeping foxtail, and reed canarygrass which were successful in extending and maintaining growth above the water surface which appears to result from a more erect growth habit. Tall fescue, tall wheatgrass, and orchardgrass struggled to extend and maintain growth above the water surface and appeared to be less tolerant of flooding. Fluctuating water levels and flooding durations will influence what grass species will be best suited to specific conditions.

Pasture productivity is greatly improved and better utilized when foxtail barley is replaced with desirable grass species that are more palatable and beneficial to grazing livestock. Selecting grass species that will successfully establish, persist, and compete in areas with adverse salinity and flooding conditions is critical to the successful control of foxtail barley. Furthermore, if desirable grass species are unable to establish in areas where foxtail barley exists, then selective herbicide control is not an option due to the fact that there are no desirable species from which to selectively remove foxtail barley.

In conclusion, results from these greenhouse studies provide some useful predictions of the expected tolerance that these selected grass species have to herbicides, salinity, and flooding. However, further evaluation and investigation needs to be tested in the field to validate and substantiate the conclusions made in this research.